MODELING THE PERFORMANCE OF FINNISH UNIVERSITIES WITH SYSTEM DYNAMICS SIMULATION

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Business Analytics, Business Administration

Master’s thesis

2022

Miia Haverinen

Examiners: Professor Mikael Collan, D.Sc. (Econ.)

Post-Doctoral Researcher Jyrki Savolainen, D.Sc. (Econ.)

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Business and Management

Business Administration

Miia Haverinen

Modeling the performance of Finnish universities with System Dynamics simulation

Master's thesis

2022

112 pages, 21 figures, 4 tables and 9 appendices

Examiners: Professor Mikael Collan, D.Sc. (Econ.) and Post-Doctoral Researcher Jyrki Savolainen, D.Sc. (Econ.)

Keywords: System dynamics; System dynamics modeling; Monte Carlo simulation; Group model building; Performance-based university funding

One of the long-standing problems of the Finnish education system is the prolonged transition of young people to the labour market with higher education. Finland is below the average of OECD countries regarding the share of young people being in higher education and Finns graduate from universities later than average. Less than half of the students complete the degree in a target time. Finnish universities are encouraged to enhance their efficiency through performance-based university funding scheme set by the Ministry of Education and Culture of Finland.

The purpose of this thesis is to describe the connection of Finnish universities' performance and government's funding scheme and to model the possible impacts of education policy changes on university productivity. System dynamics modeling and Monte Carlo simulation were applied to model the Finnish university degree system. Geometric Brownian motion was applied as a mathematical uncertainty presentation to draw alternative future scenarios of study progression. The study proves how the modern simulation methods provide a more comprehensive way to implement analysis and to test different scenarios when simulating alternative prospects also involving stochastic features. It also seems that system dynamic approach is relevant in mimicking the university degree system in which several time delays between input and output variables are involved.

As the first contribution of this study the simulation model is developed and tested, which is able to describe the degree completion and the associated times delays related to the system. Second contribution of this study is to illustrate how shortened study progresses impact on yearly graduates and from this perspective speeds the transition of young population into labour market. From the funding perspective, simulation results illustrate how smaller universities in particular can improve their competitive position in core funding by increasing the share of target time graduates.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT-kauppakorkeakoulu

Kauppatieteet

Miia Haverinen

Suomalaisten yliopistojen suorituskyvyn mallinnus Systeemidynaamisella simulaatiolla

Kauppatieteiden pro gradu -tutkielma

2022

112 sivua, 21 kuvaa, 4 taulukkoa ja 9 liitettä

Tarkastajat: professori Mikael Collan D.Sc. (Econ.) ja tutkijatohtori Jyrki Savolainen D.Sc. (Econ.)

Avainsanat: Systeemidynamiikka; Systeemidynaaminen mallinnus; Monte Carlo simulaatio; Osallistava ryhmämallintaminen; Yliopistojen suoritusperusteinen rahoitus

Yksi Suomen korkeakoulujärjestelmän pitkäaikaisista ongelmista on nuorten pitkittynyt siirtyminen korkeakoulutuksesta työelämään. OECD-maihin verrattuna suomalaisten korkeakoulutuksessa olevien nuorten osuus on alle muiden maiden keskiarvon. Suomalaiset valmistuvat keskimääräistä myöhemmin ja alle puolet opiskelijoista valmistuu tavoiteajassa. Yliopistoja kannustetaan tehokkaampaan suoriutumiseen Opetus- ja Kulttuuriministeriön säätämällä suoritusperusteisella yliopistojen rahoitusmallilla.

Opinnäytetyön tarkoituksena on kuvata suomalaisen yliopistojärjestelmän yhteyttä kansalliseen rahoitusmalliin ja mallintaa koulutuspoliittisten muutosten mahdollisia vaikutuksia yliopistojen tuloksellisuuteen. Opinnäytetyössä sovellettiin systeemidynaamista lähestymistapaa ja Monte Carlo -simulaatiota mallinnettaessa yliopistojen tutkintojärjestelmää. Geometristä Brownin liikettä käytettiin matemaattisena viitekehyksenä tuottamaan vaihtoehtoisia opintojen etenemistä kuvaavia tulevaisuuden skenaarioita.

Tutkimus osoittaa, että moderni simulaatiomenetelmä tarjoaa kattavan tavan toteuttaa analyysejä ja mallintaa stokastisia piirteitä sisältäviä vaihtoehtoisia tulevaisuuden kuvia. Kehitetyn simulaatiomallin avulla voidaan testata koulutuspoliittisten muutosten ja rahoitusmallin kannustimien mahdollisia vaikutuksia yliopistojen tuloksellisuuteen. Malli vangitsee systeemin rakenteessa olevia useita aikaviiveitä, jotka ovat oleellisia opiskeluaikaa kuvaavan prosessin havainnollistamisessa. Simulaatiotulokset korostavat, kuinka opintojen suoritusajan lyheneminen vaikuttaa nuorten nopeampaan siirtymiseen työmarkkinoille tai ylempään korkeakoulutukseen. Rahoituksen näkökulmasta tulokset osoittavat, että erityisesti pienet yliopistot voivat parantaa kilpailuasemaansa perusrahoituksesta kasvattamalla tavoiteajassa valmistuneiden osuuttaan vuosittaisista tutkinnon suorittaneista.

Table of contents

Appendices

1. Introduction

In Finland, education and research and innovation have played a key role in building prosperity and the success of the nation. As the future challenges are driven by international competition for skills, jobs, and the transformation of work and technology, a highly educated population and an efficient education system guarantees a skilled workforce in future. In addition, in terms of changing population projection, Finnish Innovation Fund Sitra (2020) predicts that if the proportion of university applicants and number of admitted students is based on the size of the age groups, the number of young applicants and students will fall sharply from the 2030s onwards due the decreased birth rate in 2010s. Still, the demand for study places for higher education will remain, as every year significant proportion of applicants are left out without a study place.

The purpose of this thesis is to model the university degree system respect to the performance-based funding scheme set by the Ministry of Education and Culture of Finland (The OKM / Opetus ja Kulttuuriministeriö) by applying the System dynamics (SD) modeling and Monte Carlo simulation methods. The research is carried out in collaboration with the OKM, which is also the client of the project. System dynamic models, in general, assists to learn about and manage complex systems by capturing feedback processes, stock and flows, and non-linearities that cause the complexity in many system structures. Monte Carlo, on the other hand, is a computational approach for probabilistic analysis, in which algorithms are used for simulation of real-life processes by following some physical system, and then providing statistical estimates of the problem relying repeated random processes.

The government's vision for higher education is more influential and more international Finnish higher education system, which targets to raise the level of education, enables continuous learning, and strengthens the intensity of research and development activities. The goal to raise the level of higher educated people requires more efficient completion of studies, whereas one of the long-standing problems of the Finnish higher education system is the prolonged transition of young people to the labour market with higher education. In particular, Finland is below the average of OECD countries regarding the share of young people being in higher education in addition that Finns graduate from universities later than average. Less than half of students complete the degree in a target time.

To identify the cornerstones influencing the effectiveness of higher education system in the constantly changing operational environment, there is a growing need for new managerial tools that enable constant reassessment of the performance of higher education institutions. As the OKM utilizes performance-based funding to allocate the core fund from government to universities based on pre-set indicators, there is also an interest to monitor the university productivity respect to financial incentives and anticipate possible future scenarios of performance if education policy changes take place. With a method that enables capturing the dynamical structure of the higher education system, new kind of education policy assessment can be conducted.

In the study, the modeling process is divided into two phases. The first step is to illustrate in a qualitative manner the Finnish university system and its connection to society in a high abstraction level using model diagrams, and to identify key variables and their possible causalities constructing the system. In the second part, parameterized dynamic simulation model is formed as a quantitative part of the study by using Matlab Simulink software. The time horizon of the simulation is the period 2020-2040. The main inputs of the model are the yearly number of new students in age-groups in each Finnish university, the percentages for different study completion times, the rate of full-time equivalent (FTE) students, degree points coefficients, the amount of the core funding and the number of person-years. The model outputs are the annual estimate of the number of graduated students by age groups and universities, the amount of core funding allocated to each university based on the indicator measuring the university productivity in terms of completed degrees, and the student-person-year ratio. Although the main study purpose is to explore the utilization of predictive models in ministry-level policy assessment, the study contribution encourages also higher educational institutions to apply the SD method in monitoring their operations.

1.1 The motivation of the study

The motivation for the research arises from the ministry-level interest to adopt quantitative modeling methods with predictive abilities to monitor university performance in a complex and constantly changing higher education operational environment. To raise the level of higher educated people requires more efficient completion of studies, which again reflects to more efficient transition of young people to the labour market with higher education. It is believed that the System dynamics approach and predictive modeling provide the means of investigating the university productivity under different conditions.

Evaluating the number of future young graduates and testing different study place allocation strategies with a capable tool could provide new insight about the problem that Finland is below the average of OECD countries regarding the share of young people being in higher education, which in turn reflects the evolution of the highly educated population. The study is influenced also by the knowledge of the population forecast, which will similarly impact on the structure of future workforce. Based on research conducted by the Finnish Innovation Fund Sitra (2020), low birth rate in the 2010s will be reflected in the late 2030s to age groups starting higher education.

It is acknowledged that university-level SD models on the topic have been already implemented a few in Master's theses in Finland (Alaluusua 2019; Vokueva 2017). These studies provide a starting point for this contribution on the research area and the development of the simulation model. However, in this study, modeling is in principle carried out to support the decision-making primarily at ministerial level providing the insight into the university performance at the national level considering all institutions in the university sector, rather than only an individual university as in the previous studies. Also, from the perspective of technical capacity, this work is believed to achieve more advanced results by using Matlab software, which is known as a high-performance language for technical computing integrating abilities to conduct data analysis, simulations, and visualizations. It is also believed that the utilization of Monte Carlo approach provides a more comprehensive way to implement sensitivity analysis and to test different scenarios when simulating alternative future processes those also involve stochastic features.

1.2 Research problem and research questions

The primary research problem is to solve, to which extent it is possible to apply system dynamic simulation model to explore the university performance in matter of study progress and the number of graduates, and secondly, using the built model, demonstrate how to predict likely consequences of educational policy changes to university performance on a national system level. The policies in this matter consider for example the financial incentives of the OKM's base funding, and the increase in the number of yearly study places.

Based on the research problem, the research questions for this thesis are formulated as follows:

RQ1: What possibilities System dynamics modeling provides in monitoring university performance on a national system level based on the existing literature?

RQ2: What kind of System dynamics model describes the Finnish university degree system and what does the model show about future developments of university productivity?

RQ3: What are the main constraints in modeling the impact of an education policy change on future university performance?

To solve the first research question, already existing simulation models in the literature devoted to university management will be examined. To tackle the second research question, qualitative model diagrams are first developed to describe the possible connections between the Finnish university system and society. After identifying key variables involved in the system, the SD simulation model will be developed in co-operation with the OKM experts. The historical data provided by the Vipunen database to conduct data analysis of the important factors affecting the study progress and graduation are obtained, based on which the simulation model is initialized. Different scenarios for simulation model demonstration purposes are defined and the results of the simulations will be then achieved and interpreted. The third research question will be solved based on the developed model and the simulation results. In addition, recent evaluation publications on the subject will be examined in terms of both, national and international reports to support the findings.

1.3 Significance of the study

The need for modern tools capable of capturing the complex higher education system is acknowledged so that more comprehensive education policy assessment could be conducted. As in the case of Sitra's recently conducted study (2020), the use of accurate computational models limits the understanding of time delays and nonlinear relationships underlying in the systems, why the SD and its ability to deal with the complexity of system structures is believed to be a suitable method to better assess the university degree system. A national-level model that enables modeling the features of the Finnish higher education system in particular, provides possibilities to track the problem of slow study completion.

In past decades, the interest in applying System dynamics modeling in university environments has been growing. Predictive models have been constructed to cover managerial problems at academic institutions (see, Kennedy & Clare 1998), some of them also covering impact of career, recruitment, and funding policies on the academic workforce (see, Al Hallak, Ayoubi, Moscardini & Loufti 2019; Gomez Diaz 2012, Kersbergen, Daelan, Meza & Horlings 2016; Oyo, Williams & Barendsen 2008; Zaini, Pavlov, Saeed, Radzicki, Hoffman & Tichenor 2017). Overall, most of the studies concentrate to model the university resource or fund allocation at the institutional level, which assist the university administration to understand their strengths and weaknesses and measure their competitiveness.

The intention of the study is to enhance decision-making capabilities from the ministry-level perspective; however, the model constructed can be applied also on the university-level use. It seems that there is no previous evidence of exploiting predictive modeling on the subject in this extent together with Monte Carlo approach, why the thesis is believed to contribute to the research topic by constructing a model that is technically competent to monitor the university performance and implement policy assessment in a dynamic manner of new kind. In addition, to the best of my knowledge, a model that captures varying study completion times of different age groups thus dealing with several time delays in the system has not yet been developed either. Respectively, a model that considers university students of different age groups and allows testing different alternative scenarios for allocating study places among these provides a new perspective for exploring the topic through simulation.

1.4 Aims and scope

To achieve the study goal, a prototype simulation model is constructed by using Matlab common workspace and Matlab Simulink. The model must be able to forecast the yearly number of graduates by age groups and universities. Sensitivity analysis is conducted to explore the university performance under varying conditions, which means that different scenarios related to the number of future study places, the allocation strategy of study places among age groups and the speed of study progress are considered. In this report, the results of the simulation model are examined with a particular focus on the young age group, meaning those who are expected to transfer to higher education after secondary education and are therefore first time in the higher education.

The simulation model developed in the study is expected to support evaluation processes in the ministerial level, but also serves as a starting point for institutional-level usage. In the latter case, the prototype model encourages universities to utilize proactive simulation modeling to monitor their own performance and later on assess internal fund allocation schemes. The developed model serves also as the starting point to implement extended ministry-driven modeling projects in future. Thus, the objective of this study is to identify the pitfalls and the best practices of the method, and to gain knowledge about the level on which the predictive models can be used to explore the consequence of financial incentives respect to the educational outcomes. The research will underline the complexity of the university system throughout the study. This means, that the research problem is solved with a sufficiently extend simulation model capable to mimicking a real-world system, however, the complexity of the model needs to be limited in respect the scope of the study.

1.5 Data and Methodology

Since the first System dynamics report conducted by Jay Forrester in 1958, the System dynamics approaches have been applied in several fields and purposes to solve complex problems, and to understand structures of systems. Originally, the SD method was developed to examine industrial supply chains, but since the evolvement of the approach, the applications have expanded to examine a variety of fields, such as economics, health care, energy production practices and environmental planning, among many others. (Sterman 2002)

The study goal is to apply SD modeling to describe the Finnish university degree system and to construct a technically viable simulation model capable of forecasting the number of graduated university students. The simulation model takes account different study completion times and the number of study places and their allocation method among different age groups at universities. In addition, the model provides as outputs the amount of allocated fund to each university and the student-person-year ratio. The main model inputs are the number of new students, percentages of different degree completion times, the number of person-years, and the ratio of full-time equivalent (FTE) students, which defines the proportion of so-called active students who are contributing studies during the academic year. The prototype model can be used to model the university performance under varying conditions and forecast the possible impact of policy changes that might have unvarying impact on different universities’ productivity.

The means of Group Model Building (GMB) combined with principles of action research method are applied to involve several experts into the modeling process. Thus, the research is conducted as a cyclical process integrating research and action in a flexible way. This kind of study process develop knowledge and understanding of a unique kind (Somekh 2005) by collecting different expertise of individuals, which is also a key in constructing the simulation model that describes the real-life system. To increase understanding about past policy changes influencing the university financing and their likely effect on the university performance, recent evaluation publications are reviewed together with statistical analyses supporting the findings.

The model developed in the study is based on quantitative data on universities available in statistics released by Vipunen, which is the education administration's reporting portal. Statistics of Vipunen are based on data and registers collected by Statistics Finland, the Ministry of Culture and Education and the Finnish National Agency for Education. The statistical service includes statistical and indicator information on education in various sectors, such as information on the number of students in higher education and information related to study progress.

1.6 Focus and limitations

As highlighted by several authors (see e.g., Cosenz & Bianchi 2013; Galbraith 2009; Kennedy 2002), universities are complex in sense that they involve non-linear connections and time delays inside of their system structure and between the system parts, why modeling this kind of entity has its own challenges The model boundaries need to be in the extent that feedback processes relevant to the problem are involved so that the main objectives of the research are reached; however, too complex model and error estimates in setting model boundaries can lead to erroneous conclusions and unreliable results as well.

As another issue, since university performance is affected by both endogenous and exogenous factors, cause-and-effect relationships which are sometimes underlying in the system are challenging to be directly assumed, which is why the real impact of financial incentives on university performance is difficult to be measured. Exogenous factors, in the context, means external driving forces that might have impact on the university outcomes, but are not directly controlled or are intangible by nature. Such factors are for example related to the economy of the country (Gomez Diaz 2012, 40), cultural practices and political legitimization of a system (Auranen & Nieminen 2010, 823). In this study, we understand that these involve also factors related to students' readiness to complete studies and student material, which might vary from study program to another. Additionally, attitudes towards learning and the effectiveness of the student services of institutions that might have influence on the study progress are difficult to be represented in the model. Endogenous factors, instead, are characteristics of the operating environment, such as staff-student ratio and the internal managerial decisions (see, Galbraith 2009, 111).

One of the limitations of simulation modeling is also the amount of data available. Although there is a comprehensive database hold by the OKM and the Finnish National Agency for Education, data providing information of degree completion times of yearly classes are only available for the short term. To draw complete probability distribution of study completion times of yearly classes that are basis for future predictions, there is need for statistics from three up to more than ten years to gain the full view of the behaviour of yearly intakes in past. Therefore, only a few of these statistics after the 2010s could be used for data analysis and initialization purposes of the model.

1.7 Structure of the thesis

The thesis is divided into six chapters. The second chapter is devoted to theoretical background. First, the performance-based university funding scheme is covered, followed by the discussion of Systems dynamics first in general, and Group Model Building as an approach of the SD-method in particular. The Monte Carlo simulation technique and geometric Brownian motion as a mathematical uncertainty presentation are also discussed. In the third chapter, there is the literature review of the most relevant theoretical System dynamics applications in university managerial planning. In the fourth chapter, there is an introduction to the Finnish higher education system in general, and to the study progression and the funding model in particular. The impact of population projection on the number of higher education students in future is also discussed. The fifth section deals with the construction of the simulation model. The causalities involved in the scheme are illustrated through the Causal Loop Diagram (the CLD) and the Stock and Flow diagram, those lead defining key variables relevant to the simulation model. The quantitative simulation model is then constructed, and Monte Carlo approach applied to test the model under different conditions. A summary about the model functionality is provided and the results of simulations are analysed. The final part of the report is devoted to the final conclusions and discussions about the study process, obtained goals, limitations, and ideas of further research aspects on the topic.

2. Theoretical background

During the past two decades in several European countries, ministries responsible for higher education have established performance-based funding systems (PBFS), in which the public budget is dependent on the performance of institution. Such mechanisms to allocate higher education funding has been also adapted in other countries worldwide, for example in Australia, Hong Kong, and many states in the USA (De Boer et al. 2015, 4-8; Jonkers & Zacharewicz 2016, 17-18, 41, Geuna & Martin 2003; Zacharewicz, Lepori, Reale, & Jonkers 2019). The funding system includes competitive elements in the allocation of organizational level funding (Jonkers & Zacharewicz 2016, 9), while it also increases the autonomy of the higher education institution (Checchi, Malgarini & Sarlo 2018, 46; Cosenz & Bianchi 2013, 7; Seuri & Vartiainen 2018, 103).

As the basis of performance-based funding models, performance agreements are those contracts between the government and universities, that set out targets that institutions seek to achieve in a given time period. The achievements of the targets are measured according to pre-established standards, that are the result of a political decision. The budget that an institution receives is calculated using the formula, which works on bases of the performance results achieved in the recent past. The aims of performance agreements are to encourage institutions to strategically position themselves and to improve core activities, referring for example to a higher quality of research and the level of productivity. The agreements also encourage to establish the strategic dialogue between the government and the institutions, with the aim to align national and institutional agendas, policies, and activities. (De Boer et al. 2015, 5, 13; The OKM 2021).

In the funding models of different countries, there are variety in indicators used in measuring the institutional performance (see, Seuri & Vartiainen 2018, 105; Zacharewicz et al. 2019) mainly due the different circumstances, inner dynamics (Adams 2020, 9), and political and economical differences of these countries (Auranen & Nieminen 2010, 828; Boer et al. 2015, 9, Jonkers & Zacharewicz 2016, 19). The performance-based funding models of some countries, for example of Finland, Sweden, and Denmark seek to strike balance between addressing global trends, such as internationalization, and upholding the egalitarian principles underlying the educational systems (Adams 2020, 9), in addition to the maintenance of welfare policy tradition (Auranen and Nieminen 2010, 828). Adams (2020, 9) highlights, that the fiscal austerity following the 2008 global financial crisis provided a perspective on efficiency planning for all public sectors involving higher education institutions, especially when tuition fees are not bringing income. In their report, Seuri and Vartiainen (2018, 103) also points to a reduction in resources in Finnish universities, especially regarding teaching staff. Since 2010, university teaching personnel has decreased from 18,400 to 17,400 by 2016. Additionally, after 2011, university funding in Finland has decreased significantly. (Seuri & Vartiainen 2018, 104-105)

Many performance-based funding systems of the countries involve education metrics, such as student enrolled and BSc and MSc graduated, in addition to indicators evaluating research performance, such as the number of publications and/or citations and peer review (see, Sivertsen 2015, 850). Other factors involved in the schemes are for example third party income, the credits earned by the students, and the collaboration with industry. (De Boer et al. 2015, 9; Checchi et al. 2018, 52; Jonkers & Zacharewicz 2016, 19) The use of performance-based funding in research funding, also referred in this case as performance-based research funding (PBRF), aims to stimulate efficiency and excellence of quality, which means more and better research with the given resource level (Mathies, Kivistö & Birnbaum 2019, 23).

Governments often implement changes to the funding system, for example by changing the indicators or their weights due the priorities of the countries (Mathies et al. 2019, 24), changing political principles, and perceptions about the effectiveness of the existing funding system (Auranen & Nieminen 2010, 828; De Boer et al. 2015, 5). In the Science for Policy report by the Joint Research Center (European Comission’s in-house science service), Jonkers and Zacharewicz (2016, 11, 42) highlight, that performance-based funding can stimulate research organisations to increase the volume or quality of their output in addition to prioritise certain field of research and develop greater interaction with industry. The authors also highlight, that such system seeks to increase socio-economic impact and internationalisation of institutions.

Some arguments have also been denoted about the connection between the financial incentives and the university outputs, in addition to the possibility to evaluate the implications of funding systems. Firstly, Mathies et al. (2019, 22) argue that performance-based funding relies on a rather simple expectation of causal relationship of the research indicator and the university research performance, as there is still relatively limited amount of information about the actual impact of indicators involved in performance-based funding scheme (see also Buckle & Creedy 2012, 45; Galbraith 2009, 116). According to Mathies et al (2019, 22), for example the causality between changes in publication patterns and the use of performance-based funding incentivising is difficult to be proven (see also Aagaard & Schneider 2017, 924), due the fact that there is often a time lag of few months to years between when the start of the publishing project and the actual time of publishing. Even Mathies et al (2019, 22) used descriptive statistics to analyse the evolvement of research outputs, external factors affecting the actual outputs were difficult to include into the analysis. Similarly, Sivertsen and Aagaard (2017, 2) discuss in their study about the consideration in what extent changes in research behaviour are attributed to a certain policy mechanism, as the mechanism functions in complex systems involving interactions with local, national, and international incentive structures.

In his study, Galbraith (2010, 99) also points out the issue concerning the long-term impact of short-term decisions, why following changes in operating environments is not unproblematic. Similarly, Auranen and Nieminen (2010, 823-824) concluded in their research paper after comparing eight countries, that direct causalities between financial incentives and the efficiency of university systems does not exist (see also Geuna and Martin 2003, 303), also highlighting the issue of time lag when implementing funding system and monitoring its results. In addition, a problematic issue when conducting assessments is the varieties in the quantity and quality of data about funding mechanisms of different countries, and the fact that funding transformations do not take place in a similar manner in the countries under comparisons. (Auranen & Nieminen 2010, 824)

Followingly, Checchi et al. (2018, 46) conducted a study to uncover the potential impact of introducing PBFS on national research systems, by using data about the number of publications and their scientific impact in sense of citations and publications in top-ranked journals for 31 countries over the period 1996-2016. The authors concluded that on average, PBFS is found to increase the number of publications, however, the effect is only temporary losing its influence after a few years. Some effect was also found to the average quality of research measured by the number of citations. (Checchi et al. 2018, 46)

Jonkers and Zacharewicz (2016, 11, 42) also report some of the considerations risen over the years about the functionality of the performance-based funding mechanisms. One criticism is that due the funding models are often imperfect in sense of their design and implementation, they may create perverse incentives and result stimulating undesired behaviour, such as scientific fraud (see also Checchi et al. 2018, 46). In addition, since policy makers prioritize certain fields or disciplines, this means that others inevitably get smaller share from the funding. Overall, all universities cannot equally compete based on the performance-based measures favoured due the design of the system, which might raise a degree of institutional resistance. (Jonkers and Zacharewicz 2016, 42)

Seuri and Vartiainen (2018, 20) also recall prudence in interpreting the impact of the funding model and incentives on university performance. The authors point out that although completion of studies would appear to have enhanced over the last decade in Finland based on the indicator that considers credits earned by students, the increase in the share of students earning over 55 credits per year is probably partly a result of tightening of study grant requirements in 2011 and 2014. Seuri and Vartiainen (2018) estimate that these would probably have had significant impact on study activity without the financial incentives, even though it is reasonable to consider that the incentive has also some consequences.

Lastly, in the recent report conducted by Finnish Union of University Professors (2021) is the evaluation of the internal funding models of Finnish universities about how these models follow the structure of national funding model set by the OKM. As stated in the report, it would be erroneous to assume that increasing the weight of the indicator in the model would directly grow the institutional productivity in the same proportion. For example, the indicator with a weight of 20 percent in the funding model may have the same effect on operation as the weight of 35 percent. Also, if several indicators are used, the overall impact of a single indicator may be less. These considerations increase the difficulty to evaluate the real impact of financial incentives set by the government.

2.1 System Dynamics

System dynamics was developed by Jay Forrester in the 1950s and 1960s as a quantitative and mechanistic approach to understand the behavior of systems over time (Andersen, Rich & Macdonald 2009, 257; Scott 2019, 784; Scott 2018, 19). As a pioneering system scientist, Forrester argued that human mind is not well capable of tracing the dynamics of complex feedback structures of the problems, why there was a need for System dynamics simulations to solve problems (Scott 2019, 783; Vennix 1999, 382) and enhance learning in a complex world (Morecroft 2007, 5; Sterman 2002, 4). So far real-world systems with detailed mathematical models were constructed and used to explore how policies and practices would effect on the system behavior (Dooley 2002, 3-5; Scott 2018, 19), and as Forrester emphasized; "to find robust policies to tackle strategic problems" (Vennix, Akkermans & Rouwette 1996, 39).

Forrester himself described the System dynamic method in 1991 as following: "System dynamics combines the theory, methods, and philosophy needed to analyze the behavior of systems not only in management, but also in environmental change, politics, economic behavior, medicine, engineering, and other fields" (Mella 2012, 92). Today, applications of System dynamics are utilized for various purposes with the aim to identify how decision streams and resources interact (Galbraith 2009, 9) and to achieve vision about alternative futures (Morecroft 2007, 5). Applications dealing with complex systems have occurred also in different levels: individual and family levels, organizational and society levels and in the level of complex socio-technical systems. The latter of these, refers to the interaction of people and technology. (Schwaninger 2020, 25)

System dynamic models helps to learn about and manage complex systems, especially behavioral data (Richmond 1991) as they enable to capture feedback processes, stock and flows, and time delays (see, Galbraith 2009, 99) that are the basis of complexity in the system structures (Aslani, Helo & Naaraoja 2014, 759; Mella 2012, 38; Sterman 2001, 17). Morecroft (2007, 25) summarizes that the aim of strategic modeling is to investigate dynamic complexity by better understanding how the different parts of entities operate, fit together, and interact. Thus, by mimicking the relationships of the system parts by models and simulations, we can predict potential problems and better avoid strategic pitfalls. (Morecroft 2007, 25)

2.2 Complex systems

The term "system" can be defined, according to Forrester (see, Schwaninger 2020, 26) as "wholes of elements, which cooperate towards a common goal". Kauffman (1980, 1) describes a system as a "collection of parts which interact with each other to function as a whole". As another description emphasizing the aspect of relationship as the main building block of a system, Shapiro et al. (1996) identified the term as "a family of relationships between its members acting as a whole". (Schwaninger 2020, 26) The origins of the systems theory evolved in the beginning in the 1920's, when a group of researchers began to study the patterns in which all different systems were organized by identifying the same general rules that occurred in the systems, despite how different they looked. Since then, system theory has provided a way to tackle complex real-world problems. (Kauffman 1980, 1)

Mitleton-Kelly (2003, 26) explains complex behaviour of a system arising from the inter-relationship (see also, Morecroft 2007, 21), interaction, and "inter-connectivity of elements within a system and between a system and its environment". For example, in a human system an action by an individual may affect other people and systems at some point. The effect has inequal impact, positive or negative, varying with the state of each related participant. Sometimes the impact is not obvious and as such, connections between action and effects are often difficult to understand (Mitleton-Kelly 2003, 26-27; Morecroft 2007, 21). The key defining feature of complexity is also the creation of new order and coherence, which is due the adaptive and evolving nature of complex systems. Followingly, such systems have ability to be self-repairing and self-maintaining. (Kauffman 1980, 30-31)

Kauffman (1980, 32) highlights that highly complex systems are usually able to process more information and they help to foresee changes in the environment more accurately. Often, they also enable learning better about the systems and respond in a more consistent manner to a wider range of changing circumstances. On the other hand, such systems have usually more subsystems to be coordinated, and more resources are needed to gather and process the information. (Kauffman 1980, 32) Nevertheless, as Morecroft (2007, 21) emphasizes, dynamic complexity does not always mean that there are thousands of interacting components, as sometimes performance difficult to understand arise from only a few parts. According to the author, the matter is about the intricacy with which the components are bounded together involving time delays, non-linearities and processes of stock accumulations. (Morecroft 2007, 21)

2.3 Mental models

Mental model refers to an explanation of someone's thought about how systems are structured and the elements within them operate. Mental model as a concept has been essential to System dynamics from the beginning of the field, as already Forrester (1961) stressed that all our decisions are based mostly on mental models (see also, Rouwette et al. 2009, 573). Accordingly, Peter Senge (2006) identified that a mental model guides person in the decision-making situation leading to an action. Thus, they work as a pattern or a theory, or a collection of routines (see, Sterman 2002, 16) influencing our way of acting as individuals. (Mella 2012, 34-35; Morecroft 2007, 376). In system dynamic modeling, as emphasized by Doyle and Ford (1998), mental models are the product achieved in the modeling process (Rouwette, Vennix & Fenning 2009, 574).

In System dynamics, mental model involves our beliefs about the networks of causes and effects that describe how a system works, in addition to the model boundary, which refers to the scope and the choice of the number of variables, and the time horizon that is considered relevant (Sterman 2002, 16). Mella (2012, 35) describes that the discipline of mental model is essential for organizational learning, because it does not only increase the group or individual's capacity to form a stock of shared knowledge (see also, Rouwette et al. 2009, 574), but it also facilitates "the process for recognizing and modifying the group mental models to collectively decide in an effective way". This means a process in which both self-learning and the assessment of group dynamics take place.

2.4 System thinking

As mental models are those that involve our beliefs about how a system works, system thinking, also referred as system perspective (see, Galbraith 2009, 100) helps to make our mental models more explicit. As Senge and Lannon-Kim (1991) summarized; "Systems thinking is a discipline for seeing wholes, recognizing patterns and interrelationships, and learning how to structure those interrelationships in more effective, efficient ways". Thus, with system thinking we can not only look at the objects but also to “see beyond, and more”. (Mella 2012, 8; Morecroft 2007, 44)

Originally, System thinking as a concept get popular by Senge (1990), as he desired to codify a way of thinking directed at systems, without focusing on means of mathematics (Mella 2012, 7). Indeed, he introduced the approach to interpret social and business world, and to construct models that are coherent enough to strive us to look for causal relationships among the interrelated variables. (Mella 2012, 7; Morecroft 2007, 37) Accordingly, Galbraith (2010, 98) and Sterman (2001, 8-9) emphasize, that instead of a linear cause-and-effect chain, in which we interpret experience as a series of events (see also, Morecroft 2007, 33) we should understand that everything is connected to everything else, and actions feedback on themselves as a circular process creating a loop. Changing our way to see systems working like this, one shifts from “linear thinking” to “circular thinking”, as referred by Roberts (1978) and Richardson (1991) (Mella 2012, 21). With such holistic worldview, one can identify high leverage points in systems. Systems thinking can also be seen as a tool for enhancing an organizational learning, as a systemic perspective helps to avoid policy resistance and improves our decision-making skills, that are consistent with long-term best interest (Mella 2012, 34; Sterman 2002, 4; Sterman 2001, 8-9).

The basic rules of System thinking are presented in the following Figure 1:

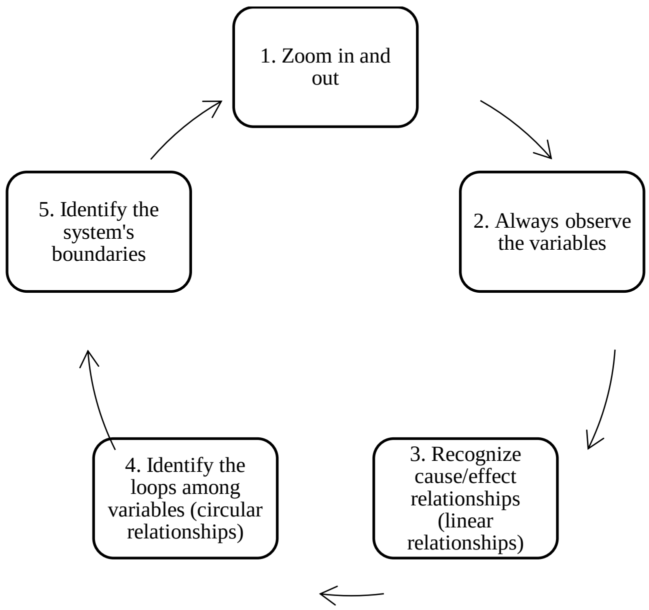


Figure 1. The principles of Systems thinking (Mella 2012, 25)

Sterman (2001, 12) explains that a change in systems occurs at many time scales those may also interact, why system thinking helps to broaden our intelligence by developing the capacity to zoom between parts and wholes and between wholes and components, that are highly interactive. This means that one needs to focus on the variables that characterize the objects, not only stop at what appears constant (Mella 2012, 10-13). For example, when one observes a flock of birds flying in the sky for a certain time period, from the system thinking perspective, instead of focusing on the bird species or from where are they coming, the interest is in about the variables from the viewpoint of their speed, the height at which the flock flies and changes in barometric pressure at different flight altitudes. The values of the variables in each time point, thus, defines the system's dynamics and the variation in the variables' values identify the behavior of the flock of birds as a dynamic system. As such, to understand the world, rather than observing only objects one must observe variables and their variations (Mella 2012, 10-13).

The important part of constructing the model is to specify the model boundaries of the system one wish to study (see, Galbraith 2009, 118; Mella 2012, 23-24), which according to Morecroft (2007, 36) is sometimes a matter of judgement and experience. The model must be wide enough involving relevant feedback processes to tackle the research problem (see, Richardson 2020, 11) but on the other hand, limited enough not to increase the complexity. As clarified by Mella (2012, 11), one need to define the variables that form the system (within the boundary) and to exclude variables that are not strongly enough interconnected to significantly influence the others (beyond the boundary).

Following the principles of systems thinking, the process performed by the system structure causes the dynamics of the variable, why it is necessary to determine this process and learn how the system structure, that produces it, works. Referring to Norbert Wiener's (1961) defined terms of "black box" and "white box", systems thinking allows one to "consider the processes that produce variations as black boxes whose internal structure and functioning might also not be known". (Mella 2012, 16) Mella (2012, 16) highlights the need to understand the connection between the inputs and outputs of the processes occurring in the black box and identify rules based to which the variations of the input variables cause those of the output variables. Those inputs we call causal variables and outputs caused variables, as effects of the causes. Mella (2012, 16) also emphasizes that to understand the dynamics of an effect variable, it is necessary to seek out causes (causes variables) assuming the process connecting them is stable. According to author, “the dynamics of a variable (output) always depends on the process that produces it through the action of it causes (input) […] In order to identify the causes of a variable’s dynamics we must construct the chain of causes and effects, stopping from zooming in when we feel we have reached the most remote cause”. (Mella 2016, 16)

2.5 System dynamics modeling

Richardson (2020, 12) emphasizes that System dynamics modeling is a continuous process as any scientific activity; it involves formulating hypotheses, testing against data, and revisioning of both formal and mental models. The modeling task begins with a problem articulation, which should provide a clear and complete statement of the problem so that the modeling process and simulation exercise can be undertaken. (Aslani et al. 2014, 760; Birta & Arbez 2013, 35; Morecroft 2007, 106; Richardson 2020, 12) The validation activity should also begin at the same state than the problem definition in order to ensure that the statement of the problem is consistent with the problem to be solved (Birta & Arbez 2013, 35). Similarly, the project goal needs to be stated so that the required level of granularity for the model is generated. The next step is to describe dynamic hypotheses meaning a preliminary sketch by the modeler of the meaningful interactions and feedback processes that potentially explain anticipated performance. Overall, the modeling process is not a linear sequence; instead, the process steps should be seen as cycle, as sometimes one needs to revisit the previous stage of work. (Morecroft 2007, 106)

Different representations of systems, from concept maps to simulation models are essential tools to evaluate consequences of new policies and the dynamics of the world (Birta & Arbez 2013, 4; Mella 2012, 29; Scott 2018, 20-21; Sterman 2002, 38; Sterman 2001, 15). According to Kim and Senge (1994), qualitative models, such as causal loop diagrams (CLDs), provide insight of the logical connections of cause and effect (Sterman 2002, 60), whereas quantitative models, also referred as empirical models, are those that explain the observed variables. The model diagram is constructed by observing the dynamics of a certain variables allowing us to learn the logic of the structure, dynamics, and changing patterns over time and in space (see, Mella 2012, 44-45), why they are sometimes called as logical models (Sterman 2002, 6).

Sterman (2002, 37) highlights that even though qualitative models allow recognizing causal relationships, they do not involve the parameters, functional forms, external inputs, and initial conditions that one needs in order to fully specify and test the model in a quantitative manner. Hence, modeling and simulating is a two-step process, in which the conceptual model is first defined guiding to the equation formulation (Morecroft 2007, 85) before the creation of the simulation program (Birta & Arbez 2013, 39). Quantitative models allow to define in graphical form these rules and functions according to which the variations of the interconnected variables cause (Mella 2012, 45-47). Especially in highly complex systems, computer simulation may be the only option "to learn effectively in a world of dynamic complexity" (Sterman 2006, 511). However, a quantitative model is feasible only in situations when deep knowledge is available, so that it is realistic to formulate a simulation model (Birta & Arbez 2013, 5).

In order to build an explanatory behavioral model unambiguous enough to reproduce the dynamic problem in a precise way, one needs to identify key variables important to the problem and decide their aggregation (Birta & Arbez 2013, 27; Richardson 2020, 12). When drawing a qualitative model, variables are connected with an arrow to characterize the relationship of an independent (causal) variable upon a dependent (effect) variable (Aslani et al. 2014, 760; Mella 2012, 49; Scott 2018, 22). The formation of a simple, open causal chain is presented in the Figure 2, in which the first variable represents the initial cause and the last variable a final effect. Such chain illustrates the linear cause-and-effect chain discussed earlier in the chapter.

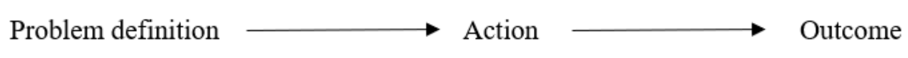


Figure 2. Example of open causal chains

2.5.1 Feedback concept

As Sterman (2002, 62) highlights, the fundamental of system thinking is that "the world is mainly composed of systems of causal loops and chains of variables" and their variations, instead of simple causal chains with an initial and final variable (see also, Mitleton-Kelly 2003, 167-168). Summarized by Kauffman (1980, 4-5), the loop has been created if "one part has an effect on the rest of the system and the system as a whole has an effect on that one part”. The term “feedback loop”, thus, describes the process, when information about the system’s output is fed back to the input side of the system.

Similarly, Richardson (2020, 13) emphasizes the feedback concept as the core of the System dynamics approach, which exists when information resulting from some action travels through a system and to its origin point in some form. This usually has influence also on the future action (see, Andersen et al 2009, 253). Feedback processes with stocks and flows, time delays, and nonlinearities discussed later in the chapter, determine the actual dynamics of a system (Andersen et al. 2009, 253-254; Sterman 2002, 12).

The loop is called a positive or self-reinforcing feedback loop if the tendency in it is to reinforce the initial action. This kind of loop drives change. If the tendency is to oppose the initial action, we have a negative, self-correcting, counteracting, or balancing feedback loop, which in the system maintains stability. (Mitleton-Kelly 2003, 37; Morecroft 2007, 40; Richardson 2020, 13; Sterman 2002, 12) Kauffman (1980, 6) emphasizes, that in every part of our natural and social environment, there are always such balancing feedback loops. The next paragraph involves discussion of examples of different feedback processes more in depth.

2.5.2 Causal Loop Diagram

Different feedback loops can be captured into a causal loop diagram (CLD), which is a visual method to describe in addition to the variables and their causal relationships, the variations, reinforcing and balancing circular processes, delays, and the system’s boundaries (Andersen et al. 2009, 253; Mella 2012, 45-46; Morecroft 2007, 39). The CLD is constructed from words, phrases, links, and loops with conventions for depicting the polarity of links naming variables. The CLD must have at least two variables and often they look like complex networks when the independent variables affect more than one dependent variable (Scott 2018, 21-22). Overall, as Richardson (2020, 12) clarifies, the aim of CLDs is to gain endogenous, behavioral view of the most meaningful dynamics of a system with the focus inward on the structures and decision rules. Thus, CLDs should be used effectively at the start of the modeling process to capture mental models and to illustrate the results of the modeling process. (Sterman 2002, 191).

The common way to explore a feedback process is to explore the heating system, which according to Kauffman (1980, 6) is the most common mechanical feedback concepts. After one has set a temperature on the thermostat, the system tries to keep the temperature as close to the set level as possible. If the temperature falls below the level, the thermostat turns the furnace on as a respond. The furnace, instead, produces heat rising the temperature again back up. In the opposite situation, if the temperature rises above the level set, the furnace turned off by the thermostat. Repeatedly, if the temperature drops again, the thermostat turns the furnace on again. Overall, we can illustrate the process with the following feedback loop in the Figure 3:

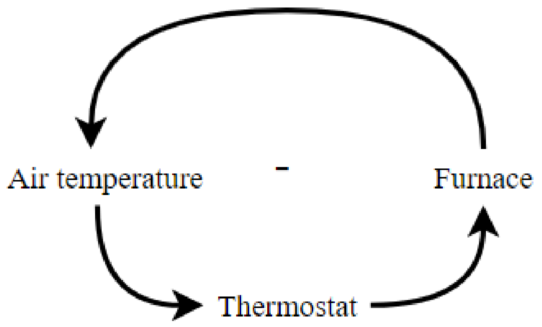


Figure 3. The feedback process of the heating system

We can identify the polarity of the loop with signs. For example, the "+" sign at the arrowheads indicates that an increase in (independent) Variable A causes (dependent) Variable B to rise above what it would have been and thus, the polarity is positive. With a similar logic, decrease causes decrease. Instead, negative "-" signs mean that an increase in the Variable A causes the decrease in Variable B beyond what it would have been. (Morecroft 2007, 39; Scott 2018, 22; Sterman 2002, 109). As an examples of positive feedback loop provided by Sterman (2002, 12), if a company lowers its price to gain market share, its competitors may respond in kind, forcing the company to lower price still more. Similarly, as an example of processes that tend to be self-limiting and to seek balance and equilibrium; the larger the market share of dominant companies, the more likely is government antitrust action to limit their monopoly power. Kauffman (1980, 8) describes that the "law of supply and demand" is one example of basic negative feedback processes in economics as it tries to keep a stable balance between the supply of something and the demand for it.

2.5.3 Stocks and flows

Sterman (2002, 191) highlights, that even CLDs are useful in modeling many situations, one of their limitations is that they cannot capture the structure of systems in terms of stocks and flows (see also, Morecroft 2007, 59). These, in addition to feedback loops, play a central role in SD modeling (Aslani et al. 2014, 760; Sterman 2002, 191). Stocks, also referred as integrals, state variables, or levels (in economics) describe the system state generating the information based on which decisions are actions are made. They provide systems with inertia and memory, as they accumulate past events. For example, the firm's inventory is a stock involving products in the warehouse, similarly than the balance in a bank account. Thus, stock is representing a quantity of material existing at the time point. (Morecroft 2007, 59-60; Sterman 2002, 192-197)

Flows, also referred as rates (in economics) or derivates, are measured over a time interval per unit of time, such as day or year. The flows are the functions of the stocks, defining how rates of change in one variable impact rates of change in another. (Dooley 2002, 14). For example, a firm's inventory is increased by the flow of production (Sterman 2002, 192-194). The flow variable increasing the stock is also referred as inputs, and flow variables decreasing it as outputs. CLDs are translated into stock and flow diagrams, which general structure is illustrated in the following Figure 4. Stock is represented by a rectangle, inflows and outflows as a pipe and the sources and sinks for the flows as clouds. In addition, valves control the flows.

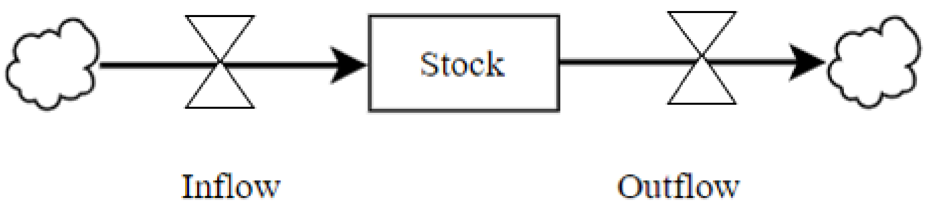


Figure 4. General structure of a Stock and Flow

Stocks accumulating or integrating their flows means that the net flow into the stock is the rate of change of it. From the integral equation (1) below one can explore, that inflow(s) is the value of the inflow at any time *s* between the initial time t_0 and the current time *t*. (Richardson 2020, 12; Sterman 2002, 194)

$$Stock(t) = \int_{t0}^{t}[Inflow(s) - Outflow(s)]ds + Stock(t0) \qquad (1)$$

Followingly, the rate of change of stock is the difference of the inflow and the outflow defined by the differential equation as following:

$$\frac{d(Stock)}{dt} = Inflow(t) - Outflow(t) \qquad (2)$$

Richardson (2020, 17) specifies that flows are those that can be changed quickly, whereas stocks usually change slowly. They rise when inflows are greater than outflows and as in opposite, decline when inflows are less than outflows. Different system behaviors are explained more in detail in the next paragraph.

2.5.4 Fundamental modes of behavior

Different feedback structures and dynamics lead to different modes of behavior of systems. The most common modes are exponential growth, goal seeking, and oscillation. S-shaped growth with overshoot and oscillation in addition to overshoot and collapse are other common modes of behavior, arising from nonlinear interactions of the fundamental feedback structures. (Morecroft 2007, 107-108; Sterman 2002, 108)

Exponential growth is due the positive (self-reinforcing) feedback process (Mella 2014, 57; Morecroft 2007, 107; Sterman 2002, 109). In simplified: the larger the quantity, the greater its net increase, further increasing the quantity leading to ever-faster growth. The more money invested results more earned interest, and greater balance continues to increase greater with the same logic. However, a positive feedback can also create self-reinforcing decline, which might happen when a decrease in stock prices undermining investor confidence, leading to more selling, lower prices, and even lower confidence. Growth is rarely completely smooth for example due the variations in the fractional growth rates and cycles. (Sterman 2002, 109)

Goal seeking (see also, Morecroft 2007, 107) is a result from negative feedback processes, those seek balance, equilibrium, and stasis in order to bring the state of the system in line with desired state (goal). Any disturbances that move the state of the system away from the goal are counterbalanced by corrective actions to solve a discrepancy between the goal and an actual state. As an example, when a company's inventory drops below the required state of the stock, production increases until inventory again reaches its ideal state to provide good service. Thus, every negative loop involves a process to compare the desired state to the actual state in order to implement corrective action. (Sterman 2002, 111-112)

When time delays between taking a decision and its effect on the system's state occur, the system can oscillate leading often negative consequences. As a simple example, when we are hungry, we often overeat since we cannot immediately recognize that we are not hungry anymore due the time delay between the eating and the feeling of fullness. Also in many other situations, people do not typically consider time delays, even when their existence are known, which leads to overshoots. Delays in feedback processes, evolved due the negative feedback processes, create instability. (Sterman 2001, 13, 116)

Sterman (2002, 116-117) highlights that the connection between the structure of the system and its behavior provides us a useful heuristic for the conceptualization process and helps generating comprehensive hypotheses about the most important loops. For example, when identifying exponential growth in a variable, there must be at least one positive feedback process dominating the system in which the variables participate. By recognizing this, we can consider the identification of self-reinforcing processes. Similarly, when identifying oscillation, there must be a dominant negative feedback process with significant time delays, after which corrective actions can be implemented.

2.5.5 Group Model Building

In the System dynamics community, different SD modeling approaches have been utilized to get insight of the systems and to foster strategic learning and change (Vennix et al. 1996, 40). Among the approaches, the importance of interactions with client groups to achieve effective implementation of model results has risen its interest during the time of System dynamics modeling (Hovmand, Andersen, Rouwette, Richardson, Rux & Calhoun 2012, 180; Rouwette et al. 2009, 572; Rouwette et al 2002, 5), as already Forrester (1961) recognized the importance of stakeholder's opinions, convictions and ideas on system functioning in accomplishing to improve the system's performance (Rouwette et al. 2009, 572). Such motivations in System dynamics modeling established later the term of group model building (GMB), sometimes also referred as participatory modeling method (Hovmand et al. 2012, 180; Scott 2019, 784; Scott 2018, 19). Later on, experiments of studies involving clients in the model building process has result an increased number of reports in the literature of the use of System dynamics as the organization's problem-solving tool (Rouwette et al. 2002, 5).

Since its existence, sometimes GMB modeling sessions involving client groups in the modeling process were led by experts while clients provided inputs to the modeling phase, whereas sometimes the models were created mostly by the clients while the experts were supporting the process. Overall, GMB approach has been used in various settings to solve a focused problem with a complex system (Hovmand et al. 2012, 180), such as for-profit, not-for-profit, government, and community organizations. Applications vary from a single modeling session resulting a qualitative diagram to sessions lasting longer time when the resulting product is a simulation model. (McCardle-Keurentjes, Rouwette, Vennix & Jacobs 2018, 355)

According to Vennix et al. (1996, 39), involving clients into the model building process is not always only to find a robust policy, but also to encourage team learning and to build consensus and commitment to future action. In other words, GMB often works as a platform for a strategic change (Vennix et al. 1996, 39), involving group-level activity during which ideas are shared affecting both, individual- and group-level-outcomes (McCardle-Keurentjes et al. 2018, 357). Overall, the approach can be the answer to messy problem that are difficult to handle, for example a situation in which there are considerably different opinions in a management team. Vennix (1999, 379) listed that in addition to enhancing the client's learning process, involving major stakeholders into the modeling process helps to capture the required knowledge in the mental models of the client group and increases the chances of implementation of model results. Thus, as Rouwette et al (2009, 574) highlight, the System dynamics model and participant's mental models are closely related.

Andersen et al. (1997) highlight the importance to clarify the intended outcomes of GMB interventions. According to the authors, there are often two separate, however, not mutually exclusive phenomenon of SD modeling: the views of *microworld* and *group dynamics.* The microworld view refers to the model as a representation of the system and modeling assist understanding and tackling complex problems. The latter view instead considers the model as a socially constructed artefact, which enhances building trust and agreement. It has been proposed that the importance of two views likely vary time to time in the process. (Scott 2019, 785; Vennix et al. 1996)

2.5.6 GMB interventions

The principles of GMB interventions follow the aspects of any SD modeling process. The key components are the refinement phase in public view of the client, developing and testing scenarios, in addition to the analysis of results obtained from the SD model. The client group is involved actively in the modeling phases. (Hovmand et al. 2012, 180) To achieve an efficient GMB sessions, there are usually several roles involving to the process, however, they are not necessarily connected to distinct persons. Usually, the group facilitator is a member in the group activity, who leads the group discussion and avoids the common deficiencies in group interactions that can have negative impact on the quality of the decision. (Hovmand et al. 2012, 181; Vennix 1999, 389) The facilitator is primarily concerned with how group meetings are done, so for example how the problem is tackled, and the way group members interact. However, the role of the facilitator is not to teach and provide answers, but rather ask questions and encourage reflection and team-learning. The right attitude and communication skills of the facilitator are thus essential. In addition, he must have process structuring capabilities, so that the construction of SD model involving various activities and cognitive tasks can be managed. (Vennix 1999, 391)

The modeller, also referred as reflector, is a person or team participating to the modeling process by concentrating to how the formal model is emerging from the group discussion. A process coach, instead, is responsible for the creation of the overall agenda for the day, whereas the recorder makes a real-time record of the discussions and decisions implemented by the group. The gatekeeper is a person from the client group having a supportive role, and characterized by Hovmand et al. (2012, 181), serves as “a bridge between the modeling team and the client team”.

Hovmand et al. (2012, 182) suggest that the GMB meetings often start with problem-finding activities or the formal introduction of simulation tools through the use of concept models. This means, that participants examine and visualize their ideas and assumptions related to the causes and consequences of the identified problem by using systems principles. Model building, in general, helps participants in the process to recall information that can be integrated into a holistic system description. For example, when one group member mentions an item in the modeling process, it can stimulate the recall of different item by another member, because mental models are usually only partial representations of a complex situation. (McCardle-Keurentjes et al. 2018, 357; Vennix 1999, 385) McCardle-Keurentjes et al. (2018, 357) suggest that this kind of cross-cueing (Forsyth 2010) is powerful for recalling unique information, for example known by only one person. As information is usually scattered among experts, cross-cueing is powerful in group decision making for complex problems. (McCardle-Keurentjes et al. 2018, 357; Vennix et al. 1996)

In the GMB process, with the help of facilitators, participants’ ideas on the problem are translated into variables, and dynamics and linkages between those are explored and used to create a model that mimic the behaviour of the system under discussion (McCardle-Keurentjes et al. 2018, 358; Scott 2019, 783). The group decides together which ideas to include in the model, which enables to see what has been discussed and helps to make sense of complex situations and to “see what is happening”. Overall, the benefit of the qualitative model is that it serves as a group memory (see also, Vennix 1999, 382), allowing more efficient communication, which in turn, results that more time can be used to discuss about other problem areas that are important to the study (McCardle-Keurentjes et al. 2018, 358-359).

In order to organize interactions with the client team to make the best use of group time and to achieve smoothly forwarding interventions, Richardson and Andersen (1997, 194) have introduced the use of “scripts”, that refers to pre-defined sets of behavior, as a description about the group session. Scripts involve detailed plans for the group meeting, usually involving agenda for smaller durations of 10 to 15 minutes. Thus, they provide a standardized approach to codify experience, allowing partitioners to compare facilitator approaches and identify, what works best in certain circumstances. Activities involved in subsequent scripts can include for example exercises to drawing graphs of variables over time, and in the latter sessions, ways to review progress made at previous meetings. (Hovmand et al. 2012, 180-183) Hovmand et al. (2012, 180-183) highlight the importance of documented scripts, as they increase transparency and replication of effective session, working also as a tool for effective collaborative planning. Additionally, documented scripts can be shared within the SD community increasing the spread of the applicability of the GMB practice.

Even GMB has been acknowledged as a powerful SD modeling technique to enhance organizational learning, some cases have occurred when applying GMB in past has not led into insights. Based on their broad evaluation of completed GMB studies in past decades, Rouwette, Vennix and Mullekom (2002, 16-17) highlight that sometimes problems occur due the lack of discussion between modeling team, why participants might gain only moderate insight into the problem but no insight in each other’s assumption. In addition, some problems common to any SD study can be denoted. For example, in some cases, models might be too complex to understand the real-world problem, or too broad to achieve focus. On the other hand, ignoring unexpected behaviour might risk the succeed of the modeling process (see also, Dooley 2002, 24). (Birta & Arbez 2013, 10-11) As Dooley (2002, 24) highlights, insufficiently specified problem and goal statement likely leads to problems during the modeling process as well (see also, Birta & Arbez 2013, 10). It is also recognized that if the level of abstraction is not adequate and techniques are not matched to the objectives of the study, GMB projects will not lead into the increase of the problem insight (Rouwette et al 2002, 16-17).

2.6 Simulation

Computer simulation, already referred in the study as a quantitative model, is growing its popularity as a methodological approach for organizational researchers to conduct new dimensions of experimentations (Dooley 2002, 2) due the emergence and widespread availability of computer power (Birta & Arbez 2013, 4). Simulation, described by Borshchev and Filippov (2004) is the process in which the model execution takes place, carrying the model through state changes over time. In this stage, one can gain a deeper conceptual understanding of mechanism of a dynamic system involving feedback processes and non-linearities (Andersen et al. 2009, 253; Dooley 2002, 7) and explore the functioning of stocks and flows (Morecroft 2007, 61). Among other authors, Dooley (2002, 2) emphasizes that the power behind simulations is, that it helps to answer the question “What if?”, meaning that instead than only gaining knowledge about backward events, simulations provide insight by moving forward into the future (see also, Andersen et al. 2009, 259).

The simulation is conducted from a dynamic viewpoint using specific software, which allows to build *virtual worlds* (Schön 1983), also called “microworlds”, “interactive learning environments” and “scaled worlds” (Sterman 2006, 511; Sterman 2002, 34) that with an appropriate calibration can perform real tasks for an organization (Dooley 2002, 6) and illustrate alternative futures (Morecroft 2007, 187). Simulations, thus, replicate the system behavior within a physical environment (Birta & Arbez 2013, 13) providing the possibility to indicate what might happen in real situation under varying conditions if interventions of simulation model were to occur (Dooley 2002, 3). Thus, simulations are powerful in conducting experiments and developing decision-making skills without environmental risks (Mella 2012, 45; Sterman 2006, 511; Sterman 2002, 34). Accordingly, they work as an effective training environment, in which experiments by the operator correspond to the real system also in sense of time meaning, that virtual time is synchronized within the real time (Birta & Arbez 2013, 13).

Simulation models can be explored based on different process types that are commonly divided into continuous event, discrete event, or Agent-based models (Borshchev & Filippov 2004; Dooley 2002, 11). System dynamics models are usually continuous-time models (Schwaninger 2020, 24), in which time advances in a continuous manner over the length of the observation time (Birta & Arbez 2013, 50). Discrete event simulations, on the other hand, models the system as a set of events evolving over time. In these processes, time advances in discrete jumps without an equal length. Agent-based models, instead, are those that involve so-called agents to describe organizational participants and their larger collective behavior. Technically, Agent-based simulation is also discrete event model, in which agents attempt to maximize their fitness functions by integrating with other agents and resources. Usually, such models focus on modeling individual agents in queuing networks, that can present for example distribution or service systems. (Borshchev & Filippov 2004; Dooley 2002- 2; Birta & Arbez 2013, 50; Schwaninger 2020, 23-24) Today, hybrid forms of modeling have been developed building bridges between continuous and discrete methods, as complex organizational systems require strengths obtained from different methods (Dooley 2002, 3, 17; Birta & Arbez 2013, 50). Also, as Brandimarte (2014, 10) addresses, from technical viewpoint, the distinction between model types is not straightforward since in continuous models, the discretization is often necessary for improving the computational feasibility.

One can also explore model types in terms of their random aspect. Stochastic models are those that involve randomness, and their behavior is determined by one or multiple random variables (Birta & Arbez 2013, 49). Deterministic models, usually related for example in engineering and financing problems (see, Mella 2014, 201) do not involve random components. When dealing with a stochastic model, based on the initial model state, it is not possible to know for sure the future evolvement of variables, and predictions are usually made for several alternative futures that are affected by the random component(s). One can then observe the regularity of events after several iterations, which helps to draw conclusions about the system behavior. During past decades, especially discrete stochastic models have become popular as they are relevant in sciences, such as in biological and physical processes (Gunawan, Cao, Petzold & Doyle 2005, 1530; Székely & Burrage 2014, 14), but also essential when simulating queuing system (see, Brandimarte 2014, 19) of for example customers' arriving times (Birta & Arbez 2013, 49). The discussion of stochastic processes in the context of simulation modeling is continued in the next section.

2.6.1 Monte Carlo simulation

Monte Carlo is a computational method for probabilistic analysis, in which algorithms are used for simulation of real-life processes by following some physical system and then providing statistical estimates of the problem relying repeated random processes (Cho & Liu 2018, 173; Dooley 2002, 1; Zio 2013, 2). Indeed, Monte Carlo approach is a useful tool to numerically explore the system behavior and anticipate future patterns under varying options, especially when one aims is to improve an existing system or design a new one (Brandimarte 2014, 3; Zio 2013, 1). Additionally, Sterman (2002, 885-886) proposes that Monte Carlo approach is powerful in conducting sensitivity analysis, as it allows to generate dynamic confidence intervals for trajectories of variables in the model, instead of observing only best and worst cases. Since the increasing computing power, the computer memory and time intensive Monte Carlo method has become feasible in the practice in various fields, such as in mathematics, physics, and engineering (Cho & Liu 2018, 173; Dooley 2002,1, 4; Zio 2013, 2).

From the technical aspect, in the Monte Carlo simulation, one can specify a probability distribution that characterize the likely values of parameters, after which a software randomly draws values for those parameters based on the distribution. Then, the model is simulated using the sampled parameter values as inputs and one can then observe several different outcomes of a particular processes after simulating the probabilities for different interactions between system parts. (Sterman 2002, 885) The proportions of approximated solution paths produced by the model can then be investigated for further assumptions about the system behavior. Sometimes, after various iteration processes, one can explore the process to behave in a regular manner even there are random components.

Mathematically, when randomness is introduced into the different equations, we forward to a stochastic differential equation (SDE), which involve so-called Gaussian noise. A one model in this scheme is the geometric Brownian motion (also called a Wiener process), which represents a continuous-time stochastic process. Such process is often utilized to model the performance of financial markets by representing the random evolution of stock prices. (Brandimarte 2014, 14) The equation of the SDE process is presented as following:

$$dS_t = \mu S_t dt + \sigma S_t dW_t \qquad (3)$$

in which *Wt* is a Brownian motion (or Wiener process), *u* represents so-called drift in the process and *q* is the volatility.

2.6.2 Model evaluation and validation

The simulation model’s structure and behavior are tested against all relevant evidence to explore the model’s ability to replicate historical data. It is important to ensure that the model is robust under extreme conditions, which means that besides that the simulation model works technically without error, the model is valid under different conditions of the system. (Dooley 2002, 27; Morecroft 2007, 383; Richardson 2020, 12) Model validity, indeed, concerns how close the computed behavior is to the real-world answer, so how well the algebraic equation is defined (Morecroft 2007, 71). However, as simulations often involve random elements as discussed previously in the context of stochastic processes, exact fit is rarely obtained or even expected. (Dooley 2002, 27)

After the sensitivity of results to uncertainty in assumptions are identified, and the sources of possible unexpected model behavior are investigated, one can make comparisons of the model outcomes to real-world policies. It is suggested that the model and its supporting sources are documented so that it is as transparent as possible and enables others to use and extend the work. In addition, working with stakeholders help to translate insight gained from the model into implementable policies. The help of implementation, results assessing, and improving both model and policies have a key role in particular in the group model building. (Richardson 2020, 12) When clients of the modeling projects are remote from the model development state, the focus in presenting modeling outcomes should not be on the model's features, but instead on the results obtained from the simulation experiment that relate directly to the project goal (Birta & Arbez 2013, 49). Therefore, for the effectiveness of the work, it is important to put the results in an understandable form so that they can be exploited.

3. Literature review

The purpose of the literature review is to find previous publications on the application of System dynamics modeling to measure university performance. Scholarly journals and conference papers are considered as the main sources of the literature review, which is conducted using databases of Scopus, Springers, Academic Search Elite, and EBSCO with advanced search functionalities. Publications are selected by considering first titles and secondly, abstracts and methodologies. As such, most relevant publications are filtered out.

To obtain productive results focused to the study topic, Boolean operators are used to combine keywords in a search. The keywords and their combinations in searching relevant publications are: “System dynamics”, “System dynamics modeling”, “University performance”, “Higher education management”, “Simulation”, “Predictive modeling”, “Monte Carlo simulation”, and “Higher education system”. The publication year is not filtered, as there is an interest to gain a broad understanding of possible different applications during past decades. Using combinations of keywords of higher education management and System dynamics modeling, 99 articles and 53 conference papers were found for example from Springers database published between 1989 and 2021. However, continuing the filtering process, in total of 24 studies are considered relevant for the literature review.

3.1 Findings of the literature review

Overall, during past decades, several studies have been conducted to examine some of the problems with the higher education management domain and the summarization of applying SD models to tackle the issues has been presented in Kennedy’s (1998, 2000, 2002) extensive survey paper. Kennedy (2000, 2002) proposes an initial taxonomy of System dynamics models in higher education, classifying different areas of concerns over hierarchical levels in university system based on the research contributions. To mention a few, the areas concern for example Corporate Governance, Planning, Resourcing and Budgeting, and Enrolment demand. The interest to apply System dynamic approach to explore higher education systems is due the reason that static linear models are inadequate for solving management problems in continually evolving, non-linear systems. As such systems are structured by interactions of closed chains and feedback loops, the SD has been acknowledged as a promising tool for higher education management. (Kennedy & Claire 1999) This section will introduce a selection of completed reports conducted to apply predictive models to tackle management issues in HE sectors.

Starting to examine research contributions on the topic in the 1990's, the Information Management and Modelling Research group developed a pilot study applying System dynamics approach to investigate quality management issues at London South Bank University in 1998. The study addresses several factors that were involved in Higher Education Quality Management, such as Staff performance, Funding, Administration, Research and Funding and Student Performance: some of these being interrelated and their occurrence depends on other activities. The relationship of the key variables important to the model of quality measurement were presented using qualitative System dynamics technique, after which a prototype model was constructed for simulation purpose. As a result, it was suggested that with System dynamics model, higher education departments can learn the likely impact of educational policies on the achievement of quality related objectives. (Kennedy 1998)

In an extended series of papers in 1980s and 1990s (see, Kennedy 1999), Galbraith explored the impact of managerial policy on higher education institutional performance in Queensland University in Australia, with focus on time delays between policy change and the results. The author identified several feedback loops in the university system respect to the circumstances that various incentive schemes have applied by Australian universities to boost the productivity of individual unit. Among other defined loops Galbraith (1998) described the (reinforcing) process by which an increase in student enrolments provides additional resources, which increase the number of academic staff, providing again more students for the enrolment, producing more additional resources. Importantly, before the loop is closed, there are delays of years involved in the system, which together with non-linearities increase the difficulty to make predictions about the system behaviour. Additionally, in his research paper published in 2010, Galbraith continued the discussion about the use of System dynamics to explore educational processes and how publicly funded institutions can develop capabilities as learning organizations. The study concentrated to the topic within higher education institutions with reference to the Australian and British contexts. Galbraith (2010) provided a presentation of a model for an institutional decision-making process to identify their behavioural consequences. In particular, the focus was to illustrate systems models developed to generate cyclical behaviours that a university often exhibits over time for example in terms of faculty staffing and budgetary conditions. The author emphasized in his study again the issue about time delay between the short-time decision and the actual (long-term) impacts on the results. He also highlighted the importance of the endogenous point of view meaning, that internal (non-systemic) decisions made by the organizations have fundamental role in evolvement of problems, even though external factors can provide a combined effect. Galbraith (2010) also emphasized that the model boundaries need to be sufficiently wide to map all feedback processes relevant to the problem.

Frances, Alstyne, Ashton and Hochstettler (1994) studied how System dynamics applications can improve planning and budgeting for higher education in Arizona and Houston area with the focus of the study on enrolment demand. System dynamics model was constructed to investigate strategies for generating new enrolment demands amongst Houston's Hispanics and African American population. Simulation model was built to regulate student enrolment in Arizona area, and it was found that demand for higher education is likely to grow. To meet the growing demand, the Arizona area would receive government funding for the establishment of a new college and the implementation of a reformed curriculum model. In addition, a model was built for the Houston university system to predict the growth in demand for higher education in different regions. In the Houston area, on the other hand, the proportion of segment of college-aged people historically often applied for higher education was declining. The original model looked at higher education by age group in different ethnographic groups. Based on the findings, the focus of the modeling was shifted to capacity planning, which seeks to address how the demand for higher education can be increased among Hispanics and African Americans. It was learnt that despite the fact that if a system is on a slow-growth path and it is difficult to alter the course of the path, System dynamics can assist identifying the areas where policy or management changes have the potential of being most effective in obtaining desired goals. The conducted study also highlights the possibility of SD to help communicating society's knowledge needs to political stakeholders.

Continuing the 20th century, Barlas and Diker (2000) constructed an interactive dynamic simulation model on which the academic aspects of university management can be analysed together with possibility to test alterative management strategies. The SD-model developed focuses on long-term problems having a dynamic structure, such as student growth, faculty ratios, teaching quality and low research productivity. Model diagrams were first utilized to describe the connections involved in the university system and the parametrized simulation model was run using input values taken from Boğaziçi University in Turkey. Followingly, the authors converted the university management simulation model into a 'UNIGMAE' simulation game with which the university activities can be guided on the basis of indicators measuring university performance. and results obtained from the game demonstrated the complexity of dynamic feedback processes and counter-intuitive nature of the system. The technology promises to be useful to support strategic decision management and works as a laboratory for theoretical research on how to best deal with complex university problems.

Casper and Henry (2001) apply System dynamics approach for supporting the allocation of instructional resources within a public university sector and, in Kent State University in Ohio in particular. The model developed in the study focus on expenditures and resource planning from the perspective of equipment distribution between university departments. In detail, the authors defined for the equipment allocation so-called relative equipment intensity with three levels for each department, used also in calculations. The performance-oriented model discussed in the study includes shares of full-time equated students and full-time equated faculty as performance variables, used in algorithms. The paper demonstrated that instead of using only ad hoc approach to resource allocation, modeling decision-making parameters will lead the better insight into the system.

Oyo, Williams and Barendsen (2008) presented a System dynamics model to examine the impact of managerial policy in higher education institutional performance in the context of the developing countries. The authors highlighted that in the developing world in general and in Uganda in particular, there are no straightforward dependencies due ad-hoc reactions to reduced funding providing thus own complexity into the system. The authors explored the university systems with model diagrams and the resulting simulation model was used to review policies on funding and quality in higher education with the possibility to be adapted also to higher education planning in other environments. The authors highlighted among other issues, that in developing countries higher education has been evolving in reaction to pressures of rapid growth of enrolment and deteriorating physical facilities. The research adopted the SD approach to investigate the dynamics of the HE funding and the impact on part-time teaching, staff to student ratios and staff development in addition to research productivity and the perceived quality. The completed study demonstrates the usefulness of the SD tool over traditional computational methods in learning the dynamics of the system, escalated by the nature of quality in terms of its non-linearity, complexity, and feedbacks.

Dahlan and Yahaya (2010) addressed the problem to manage complex academic resources of universities in general and in Malaysia University of Science and Technology in particular. In their study, the authors determined factors that form the basis of a decision support system (DSSs) for meeting the supply and demand of an academic program, such as the lecturer to student ratio. They also addressed key factors, those balance is often influenced by temporal changes of internal and external educational policies, and through which the need for quality education in HE institution is addressed. These include organization and resources; students and their support; teaching and learning; curriculum; funding; research; and management and quality control policies. The System dynamics method, including the illustration of stock and flow diagram and simulation models, was utilized to empower institutions to dynamically evaluate strategies, generate forecasts and plan their factors. The authors simulated the developed model iteratively using the input data provided by the university, and with such model, it become possible to solve different problems related to academic capacity planning, such as determine the best admission capacity of a degree program.

Barber and López-Valcárcel (2010) developed a supply and demand SD simulation model to forecast the need for medical specialists in Spain with the goal to simulate the consequences of different policies aimed at enhancing the capacity of the Spanish health system. The problem of a shortage of medical doctors in the country was highlighted and the need for tools for long-term planning for health professionals was addressed. The constructed SD model involve demographic, education, and labour market variables. Additionally, user-defined variables that health planners could control provided a possibility to simulate different scenarios. The SD model suggested the need to increase the number of students admitted to medical school in order to increase the number of medical specialists in the country. The study emphasizes the use of system feedback modeling for policy analysis in a complex social and ecological environment and a plurality of perspectives. To be mentioned, the developed SD model was utilized in the planning practices of the country, as the initial model version helped to design some changes for example of the number of training positions of medical specialists.

Önsel and Barlas (2011) applied System dynamics simulation tool in Bogazici University in Turkey to analyse what performance measures may improve and harm the research output performance of researchers. With a simulation model, authors seek to investigate the long run publication behaviour of faculty members under some assumptions and to see the effects of some managerial policies on the publication practices. The causal loop diagram was first drawn to illustrate the relations between key variables in the model, involving variables related to reputation of the faculty, skill level, time devoted to research activities, the fraction of the papers and the publication and citation pressure. With scenario analysis, Önsel and Barlas (2011) tested for example the effects of increasing skill level of the faculty members to publication performances and how time to research effect on research productivity. The key findings of the study are, that increasing skill level of faculty members increases publication and citation performance and increased focus on government funding would lead to a larger workforce, but not to a research output. It was also found, that devoting more time to research increases research productivity.

Gomez Diaz (2012) constructed a SD- model in United States to test how increase in research funds affect to the outcomes in terms of workforce development. The simulation model was calibrated to replicate historical trends and it performed experiments with the focus on testing the impacts of changes in certain parameters or policies. The resulted model demonstrated that in dynamic social systems, assumptions of causalities are not always correct, as in the study, the public research budget increase did not lead to the desired development of workforce. Indeed, the SD model results indicated that a sharp and temporary rise in funding can result in unintended long-term effects hampering research discoveries and workforce development in the National Institutes of Health. The study emphasizes, that positive policies might not be as effective in reality and can oppositely worsen the system's conditions. As the keynote of the study, the SD model that allows running simulation experiments and ask "what if" questions before actual policies are useful in a manner that potential pitfalls can be avoided.

Ishikawa, Ohbam, Yokooka, Nakamuri and Ogasawara (2013) determined a criterion for evaluating whether the number of physicians is sufficient in Japan using SD approach as a forecasting model. The country copes with a medical issue of a shortage of physicians who have a key role in healthcare provision and SD model was developed to forecast the number of all clinical physicians respect to the number of medical student enrolments. The study points to a reduction in medical school enrolment quotas, which is a major factor behind the physician shortage. With evaluations and sensitivity analysis, authors could emphasize that the number of physicians would increase during 2008-2030 and the shortage would resolve in 2026 for all clinical physicians. Ishikawa et al. (2013) suggested a need for measures for reconsidering the allocation system of new entry physicians to resolve maldistribution between medical departments and for increasing the overall number of clinical physicians. The study increases the contribution of research to the use of SD method to assist health policy planning for human resources.

Robledo, Sepulveda, and Archer (2013) applied System dynamics and Agent-based simulation model to illustrate the enrolment process at the university level in general, and enrolment, retention, and major's selection at the department level in particular. The authors emphasize the SD technique's capability to forecast more accurately the amounts of students for next term or year, in addition to class assignments and faculty hiring. Other resource allocation problems were also addressed. The authors highlight the need to see universities as highly complex, interactive, and sometimes unpredictable systems that depend on several exogenous and endogenous factors, and if necessary, changes in operations are not foreseen with enough time, long-term goals may suffer. It was also noted that todays' decisions may not have an immediate impact in lower operational level, causing problems when changes need immediate actions. Overall, the developed model was promising in terms of its capability to track student enrolment system respect to the capacity planning.

Cosenz and Bianchi (2013) demonstrated in their study, how identifying feedback processes between end-results, university performance drivers and strategic assets in academic institution can improve the ability of its decision-makers to manage and measure organizational performance. The authors highlight the importance of identifying administrative products, mapping the underlying processes, and matching them to key-responsibility areas in order to achieve an effective implementation of performance improvement programs in academic institutions. The authors proved that combining System dynamics models with performance management provides possibilities to better identifying and measuring key-performance indicators and to effectively influence policy levers to pursue a sustainable development in universities.

Vanderby, Carterm Latham and Feindel (2014) developed a forecasting model in Canada to advance planning of health human resources (HHR) training to ensure that the need of population is met in the future. The study emphasized the fact that the education programmes for experts in the health care sector require more than 10 years, why the system cannot respond quickly to changing health care provider requirements. Accordingly, feedback processes defined in the study capture the impacts of workforce shortages on productivity and unemployed graduates on program enrolment. The constructed SD model with population demand and the provider supply components is promising in a manner that it could give health care providers, students and external stakeholders insight into the effect surgeons' workload decisions and student enrolment decisions have on the system.

Strauss and Borenstein (2014) developed a SD model with the aim to help higher education policymakers to better understand the dynamics of the undergraduate education system in Brazil. In their study, authors contributed to integrate in an SD model the aspects of the strategic role of HE, the regulatory policies and legislation and the impact of the environment's parameters and variables, referring to the macroeconomic and demographics aspects. The study considered political matters, budget constraints, different curves of vacancies and fluctuations of enrolment in addition to quality issues. Scenario analyses were implemented to evaluate long-term policies given by the different behaviour of issues under consideration. Model diagrams together with parametrized simulation model were promising in illustrating higher education systems.

In their study, Asl and Zendleh (2014) focused to measure the demand for Bachelors, Masters, and PhD degree students at the Iranian university by applying the System dynamics approach for the strategic university planning. The objective of the study included identifying internal and external factors which influence student demands at the case university. The authors illustrated through model diagrams key variables affecting the behaviour of student demand before the simulation phase. As an example of identified positive loop in a system, it was noted that by increasing the number of students, university income increases and that again affects educational quality. In addition, by promoting the educational quality of the university, academic motivation is enhanced leading that the numbers of students who aims to continue their education are increased. Again, this effects on university income through the increased number of students. The simulation model results show that the university will face reductions in the numbers of degree studies in all degree levels in future.

Kersbergen, Daelan, Meza and Horlings (2015) constructed a System dynamics model that describes the influence of funding regimes and career policies on the workforce development and research output over time in universities in The Netherlands. The authors aimed to represent with the model the flows of researchers into and out of different stages of academic career and perceive the effects of career and funding policies on the population and output of the researchers. After conducting what-if analyses of policy alternatives using simulation model, as a key finding it was highlighted that increasing the retirement age gap of academic staff would destabilize the temporary researcher workforce. The study highlights the System dynamics simulation as a promising way to capture dynamics of the science system, but still, faces some limitations as well regarding to the boundary setting of the model, as some variables were limited out from the model.

Dandagi, Bhushi, Badogi and Sinha (2016) examined in their study the causal relationship between factors for strategically governing a technical university in India. The authors constructed a System dynamics model with the help of causal relationships established first in the structural equation model to study the dynamic behaviour of the system. The simulation model results help the university administration to gain insight into the dynamic nature and complexity of the university system. One of the key findings of the study is that the university's adaptability to dynamic environment is influenced by the strategic orientation of its own.

Zaini, Pavlov, Saeed, Radzicki, Hoffman and Tichenor (2017) applied System dynamics to help university decision-making. The authors involved different stakeholders into the study in order to capture and convert their existing mental models into a SD-model. The case university in United States faces financial problems, why university administration suggests growing the number of student enrolment to gain more income through tuition fees. As one of the university faculties is struggling with the decreases teaching quality, the proposal faces resistance since the number of students will likely weaken the quality of teaching even more. As another issue, limits in teaching facilities are addressed. System dynamics model is constructed to describe the system involving personnel, students, and teaching facilities. Even the modeling process did not lead to the clear proposal for solving the problem, Zaini et al. (2017) highlight that System dynamics approach helps to engage stakeholders into the modeling process, as important aspects are taken account when building the model.

Al Hallak, Ayoubi, Moscardini and Loufti (2019) investigated the dynamics of student enrolment in the Syrian private higher education sector. The authors constructed a simulation model to examine dynamic interactions between student flows, staff ratios and investments in facilities. Based on the results of the simulation model, the authors suggested that the case university of the study should not change the university tuition fees as in a long run, an increase in fees might deter students from applying and on the other hand, a decrease in fees might affect the university reputation in a negative way. The simulation model developed in the study is not necessarily applicable only in private university sector and thus, works as a flexible decision support system, that helps to tackle issues related to student enrolment also in public sector by making some changes into the model if necessary. The administration of university can apply the simulation model to create different future scenarios for example by involving changes in student numbers or staff-student ratios.

The university system in Finland in particular, has been also studied applying System dynamics approach and simulation models mostly in the level of Master thesis. Vokueva (2014) explored with a simple System dynamics model how the number of graduated students and the number of university's research papers depend on certain factors that are under the control of university management. The focus of the study was mainly on the relationship between the number of professors and the university outcomes: graduate students and scientific publications. Vokueva (2014) notice that when modeling the total number of students and degree graduates, the modeling process is not linear likely due the fact that delays between enrolment and graduation might vary. With the resulted simulation model, the author tested different scenarios in which the number of academics were changed to see variations in the outcomes such as the number of graduated degree students and the scientific publications. However, some limitations were faced due the inconsistent data used in the model in addition to the fact that the information reflected a short time period, why it was a challenge to conduct regression analysis and derive accurate equations. In addition, since the simplified model, the study did not involve other possible drivers that might affect to the outcomes, such as the number of graduated students and the research activities. However, the study is promising starting point to continue modeling the topic in Finnish university environment.

As another completed Master thesis related to the topic in Finland, Alaluusua (2020) created a simulation model linked to a higher education funding system that can be used for what-if scenario analysis and to optimize university activities in Finnish universities. The System dynamics modeling method was utilized with the purpose to understand the dynamic systems of the university and to find system parts important to improve performance of the University of Oulu in particular. After modeling the university system with a qualitative technique, a parameterized dynamic simulation model was formed to describe the degree system, which is connected to the university funding system of Ministry of Education and Culture in Finland. Such model can be used to describe the operation of the degree system, involving student flows, to different stakeholders and present how the degree system relates to the university funding agreement. The simulation model serves also as a good starting point to conduct further System dynamics simulation models within the topic in Finland.

3.2 Summary of the literature review

The summary of the literature review and the main findings are presented in the following Table 1.

Table 1. The summary of the literature review

Document title	Focus of the research	The aim and scope	Results and key findings
Using System dynamics Technology to Improve Planning and Budgeting for Higher Education: Results in Arizona and Houston, Texas (Frances et al. 1994)	Higher Education Capacity Planning and Budgeting	To develop SD simulation model able to regulate student enrolment in Arizona area.	The resulted SD model help in capacity planning by identifying the future demand of study places and assist communicating society's knowledge needs to political stakeholders. It is acknowledged that SD is helpful in altering the course of path in case of a system with a slow-growth path.
A pilot System dynamics model to Capture and Monitor Quality Issues in Higher Education Institutions: Experiences Gained (Kennedy 1998)	Higher Education Quality Management	To develop a SD model as a pilot study to assess the feasibility of modelling the complex HE system to tackle quality issues in several areas	A resulted prototype model can determine the level of quality of HE areas over time. The value of SD method to HE management is addressed, and the study serves as the starting point to conduct further research on the topic.

Some Issues in Building System dynamics Models for improving the Resource Management Process in Higher Education (Kennedy & Clare 1998)	Higher Education Resource Planning and Budgeting	To continue to examine issues in the Resource Management process in HE institutions using SD applications.	The study emphasizes that the SD model is useful in the resource allocation process and help management to investigate the impact of specific policies before their implementation.
System dynamics and university management (Galbraith 1998)	Higher Education Resource Planning and Budgeting	To explore the impact of managerial policy on higher education institutional performance using SD method	Several feedback processes important to the HE system are identified that assist to tackle the managemental problems related to resource allocation.
System dynamics: A lens and scalpel for organizational decision making (Galbraith 2010)	Higher Education Process Evaluation and Resource Planning	To develop a general dynamic model to describe the university system.	System dynamics approach is found to be useful in addressing issues that emerge in the management of universities. The issue with time delay between the short-time decision and the actual impact on the results is emphasized.
A dynamic simulation game (UNIGAME) for strategic university management (Barlas & Diker 2000)	Quality Management, Faculty Ratios, Research Productivity	To construct an interactive game based on SD method to test the implications of different strategies with the focus on long-term, dynamic problems in the HE system.	The results of the game provide demonstration of dynamic feedback complexity and counter-intuitive nature of the HE system and helps the implementation of strategic decision-making processes. The model is able to examine a range of problems related to quality issues and productivity of HE.
Developing Performance-Oriented Models for University Resource Allocation (Casper and Henry, 2001)	Resource Planning	To develop a mathematical model to supporting the equipment allocation and finances between university departments.	The use of performance-oriented models (with weight parameters) of a one-time fund allocation is highlighted as promising method. The resulted model helps the university management in resource planning between departments.
A System dynamics Tool for Higher Education Funding and Quality Policy Analysis (Oyo et al. 2008)	University Funding, Resource Planning	To develop SD model to present the dynamics of HE funding system and the impact of the resource allocation.	The study demonstrated the usefulness of SD tools to learn the dynamics of higher education and to tackle to quality issues, escalated by the nature of non-linearity, complexity, and feedbacks processes.
A System dynamics Model for Determining Educational Capacity of Higher Education Institution (Dahlan and Yahaya, 2010)	Resource Allocation, Capacity Planning	To develop a SD model that enhances the resource planning in the Higher Education institution.	The resulted SD model describes factors forming the basis of a decision support system (DSS for meeting the supply and demand of an academic program, which directly contributes to efficient resource management.
Modeling the dynamics of academic publications and citations (Önsel and Barlas 2011)	Research Productivity and Quality Management	To apply SD model to analyse what performance measures may improve and harm the research output performance of researchers.	The SD model results demonstrate that increasing skill level of faculty members increases publication and citation performance. Also, increased focus on government funding would lead to a larger workforce, but not to a research output. Devoting more time to research increases research productivity.

Unintended Effects of Changes in NIH Appropriations: Challenges for Biomedical Research Workforce Development (Gomez Diaz 2012)	University Financing, Research Productivity, HR Management	To apply SD modeling to test what effect an increase in research fund results in terms of university outcomes	The resulted SD model demonstrate that in dynamic social systems, assumptions of causalities are not always correct, as in the study, the public research budget increase did not lead to the desired development of workforce. The study highlights the importance of policy testing using SD simulation before the actual policy implementation.
Hybrid simulation decision support system for university management (Robledo, Sepulveda, and Archer, 2013)	Resource Planning, Enrolment and Retention Rate Evaluation	To apply SD method and Agent-based modeling to explore the student enrolment in university level, and enrolment, retention, and major's selection at the department level.	A developed hybrid model enhances decision-making processes in university in terms of resource allocation planning. The model predicts university and department-level enrolment and retention rates for the next year.
Designing Performance Management Systems in Academic Institutions: a Dynamic Performance Management View (Cosenz & Bianchi 2013)	Performance Management	To use SD model to identify key-performance indicators and corresponding drivers, in addition to strategic resources affecting them	It is demonstrated that identifying feedback relationships between end-results, university performance drivers and strategic assets in academic institution can improve the decision-makers' ability to manage and measure organizational performance.
A System dynamics model for long-term planning of the undergraduate education in Brazil (Strauss & Borenstein 2014)	Capacity Planning, Performance Management	To developed SD model that assists HE policymakers to better evaluate the dynamics of the undergraduate education system	The developed SD prototype model encourages to use the method and implement scenario analysis to understand the complex dynamic behaviour of the HE system. The SD technique is acknowledged to be flexible tool and can enhance the planning processes of HE management.
Strategic plan compilation using System dynamics modeling (Asl and Zendleh 2014)	Capacity and Financial Planning, Student Enrolment Evaluation	To apply SD modeling to measure the demand for bachelors, masters, and PhD degree students.	The resulted SD method allows to capture several feedback processes involving in the HE system, that again effect on the number of students and educational quality. The SD results help indicating key factors affecting to the university performance and income. The simulation model results show that the university will face reductions in the numbers of degree studies levels in future.
The Impact of Career and Funding Policies on the Academic Workforce in The Netherlands: A System dynamics based Promotion Chain Study (Kersbergen et al. 2015)	Performance Evaluation, Human Resources Management	To apply a SD model to describe the influence of funding regimes and career policies on the workforce development and research output over time.	The SD results indicate that increasing the retirement age gap of academic staff would destabilize the temporary researcher workforce. It is demonstrated that simulation experiments with what-if analyses are promising in capturing dynamics of a science system.

Strategic management of Technical university: structural equation modelling approach (Dandagi et al. 2016)	Performance Evaluation	To apply structural equation modeling and System dynamics for strategic management for technical university.	The developed model is capable to capture causal relationship between factors for strategically governing a technical university. The model results help the university administration to gain insight into the dynamic nature and complexity of the university system. It is concluded that university adaptability increases with increasing strategic orientation.
Let's Talk Change in a University: A Simple Model for Addressing a Complex Agenda (Zaini et al. 2017)	Financial Planning, Quality Management	To develop a System dynamics model to describe the university system (personnel, students, and teaching facilities) with the aim of enhancing university decision-making processes and strategic planning.	The modeling process did not lead to a clear proposal for solving financial problems, however, the SD approach is acknowledged to be useful in engaging stakeholders into the modeling process.
A system dynamic model of student enrolment at the private higher education sector in Syria (Al Hallak et al. 2019)	Student Enrolment, Financial Planning, Capacity planning	To construct a simulation model to examine dynamic interactions between student flows, staff ratios and investments in plant and facilities.	The model results indicate that an increase in the university's tuition fees might deter students from applying to university and on the other hand, a decrease in fees might affect the university reputation in a negative way. The developed SD works as a flexible decision support system, that helps to tackle issues related to student enrolment in public and private sectors.
Forecasting the need for medical specialists in Spain: application of a System dynamics model (Barber and López-Valcárcel 2010)	Capacity Planning, Policy Evaluation	To apply simulation model to forecast the need for medical specialists in Spain and to simulate the consequences of different policies aimed at enhancing the capacity of the Spanish health system.	The SD model suggest increasing the number of students admitted to medical school in order to increase the number of medical specialists of the country. The study emphasizes the use of system feedback modeling for policy analysis in a complex social and ecological environment.
Forecasting the absolute and relative shortage of physicians in Japan using a System dynamics model approach (Ishikawa et al. 2013)	Capacity Planning, Human Resources Management, Health Policy Planning	To develop SD model to forecast the number of clinical physicians respect to the number of medical student enrolments.	The SD model and sensitivity analysis results indicate that the number of physicians would increase during 2008-2030 and the shortage would resolve in 2026 for all clinical physicians.

Modelling the future of the Canadian cardiac surgery workforce using System dynamics (Vanderby et al. 2014)	Capacity Planning, Human Resources Management	To apply forecasting model to advance planning of health human resources (HHR) training	The constructed SD model is promising in a manner that it could give health care providers, students and external stakeholders insight into the effect surgeons' workload decisions and student enrolment decisions have on the system.
Model-based University Management: System dynamics Approach (Vokueva 2017)	Performance Evaluation	To apply System dynamics model to evaluate how the number of graduated students and the number of university's research papers depend on certain factors controlled by the university management.	The resulted SD simulation prototype allows testing different scenarios in which the number of academics can be changed to see variations in the university outcomes. The study serves as a promising starting point to conduct further SD projects in the topic in Finland despite the fact, that some limitations of the data usage and simplified model structure lead to inaccurate results.
Rahoitusmalliin kytketyn yliopistokoulutuksen simulointi (Alaluusua 2019)	Performance Evaluation	To apply SD modeling to explore the dynamic systems of university and enhance university performance	The developed simulation model linked to a HE funding system is useful in conducting what-if scenario analysis and to optimize university activities. The model is promising in the institutional level usage and serves as a good starting point to continue exploring the dynamics of HE system in Finland.

The literature review supports the notion of SD modeling as a promising strategic planning and performance evaluation tool for higher education management, since the technique allows a long-term analysis of the system behaviour with the visualizations. However, many of the papers also address the challenge to develop an accurate simulation model to describe the highly complex university system, as cause-and-effect relationships are rarely directly measurable. It is also emphasized that since causalities are often underlying involving non-linearities and time delays, in the simulation phase it is often challenging to capture the realistic time gap between the action and the result.

Most of the papers presented in the literature review focus mainly on modeling the university level performance and solving institutional level financing, resource, or capacity planning problems. Many of those emphasize the planning of universities' internal resources in response to both, external and internal factors affecting the university performance. In addition to university financing, many of papers devote issues related to human resource management. Also, some studies contribute to evaluate the research productivity in terms of the number and quality of scientific publications. Student enrolment and study place issues that effects on the future workforce capacity are also covered.

To the best of my knowledge, a System dynamics simulation model together with Monte Carlo simulation approach to describe the dynamics of degree completion system and to forecast the number of university graduates and in this extent has not yet been applied. However, couple of papers published in other countries are recognized to share similar research objectives. For example, Frances developed already in 1990s' a SD simulation model able to regulate student enrolment in Arizona area with promising forecasting results. Similarly, the research conducted by Strauss and Borenstein (2014) in Brazil contributes to apply SD modeling to assists HE policymakers to better evaluate the dynamics of the undergraduate education system respect to the demographic rates and government policies of regulation. The authors address the government's goal to increase the number of young people with higher education, which also plays a key role in the study on hand. In addition, Al Hallak et al. (2019) applied a SD model to explore the student enrolments in Syria and even though HE systems between countries differ, feedback loops identified by authors share similarities with the Finnish university system. For example, increasing the amount of profit through the tuition fees (Syria) or public fund (Finland) will feed back to the system boosting again the internal resource allocation of the university. However, it should be mentioned that the Monte Carlo approach used in this study creates a new kind of contribution to the research area, and more comprehensively implemented sensitivity analysis is expected to provide new insights into the applicability of the SD method in the field. In addition, from a technical point of view, it is believed that the simulation model implemented in the Matlab environment provides efficient solutions for a SD project as well as for the utilization of the Monte Carlo method.

4. The higher education system in Finland

Finnish higher education system consists of 13 universities that operate within the administrative branch of the Ministry of Education and Culture (The OKM). Two of these are foundations pursuant to the Foundations Act and the others are corporations under public law. In addition, higher education degrees in the military sector are completed at the Finnish National Defence University, which operates under the defence administration. In addition to universities, 22 universities of applied sciences operate as public limited companies in the Ministry of Education and Culture's administrative branch. There are also two other universities of applied sciences: Högskolan på Åland (Åland University of Applied Sciences) and the Police University College, whose operates under the mandate of the Ministry of the Interior. The basic task of the universities is to engage in scientific research and provide the highest level of education based on it. The education in Finland is free at all levels from pre-primary to higher education. (The OKM 2021)

The governance structure of universities was changed in 2009, as universities become independent legal entities. Whereas Tampere University of Technology and Aalto University became entities under private law, other institutions become public corporations. (De Boer, Jongbloed, Kottmann & Vossensteyn 2015, 63) Even activities of universities have been since the change based on extensive autonomy and the freedom of science, the Ministry and institutions interact continuously negotiating at the start of each four-year agreement period of core funding. The goal of such negotiation is to outline common objectives for the university system, identify key measures, tasks, and degree objectives, and cover emerging scientific fields in each university. (The OKM 2021)

Universities in Finland offer Bachelor’s and Master’s degrees, and academic, artistic and third-cycle postgraduate degrees. They also provide professional specialisation studies, which involve modules in the form of open studies or other types of separate studies, in addition to continuing education. Master’s degrees are completed after a Bachelor’s degree or equivalent studies taken in the university of applied sciences. Postgraduate degrees, including Doctoral and Licentiate's degrees, are completed after a Master's degree or equivalent studies. The workload of studies is determined using credits, i.e., workload of one full year of studies corresponds to 60 credits. (the OKM 2021)

After the student admission reform in 2018-2020, higher education institutions in Finland have shifted admitting the most of their students based on secondary education certificates instead of using entrance exams for admissions. Universities have adopted more and more common admissions exams for different subjects, whereas polytechnics have introduced a common admission examination. Additionally, the time required to prepare for the admission exams are today shorter. By this, the applicants can apply for different study programmes without having to prepare for several admissions exams. Also, traveling to different localities is no longer mandatory. The aim of the student selection reform was to speed up the transition to higher education as well improving the allocation of study places. The goal of the government is to develop a high-quality, effective, and internationally competitive higher education system in Finland by the year 2030. The main goal is that 50 percent of people in age group 25-34 years have completed a tertiary degree by 2030. tThe OKM 2021)

4.1 University degrees in Finland

The share of higher education graduates in Finland has grown the slowest among OECD countries in past decade. In 2018, 41 percent of the age group of 25-34 years graduated meaning that Finland ranks close to the EU average and below the OECD average in international comparison. According to the OECD's Education at Glance report published in 2020, the share of people with higher education in the 25–34 age group has increased by two percentage in Finland in ten years, while at the same time the share in OECD countries has increased by nine percentage and in EU countries by ten percentage. A considerable part of other countries, the share of those who have completed at least a lower university degree is higher than in Finland. (The OKM 2019) The number of completed university degrees in Finland during 2000-2020 is presented in the following Figure 5.

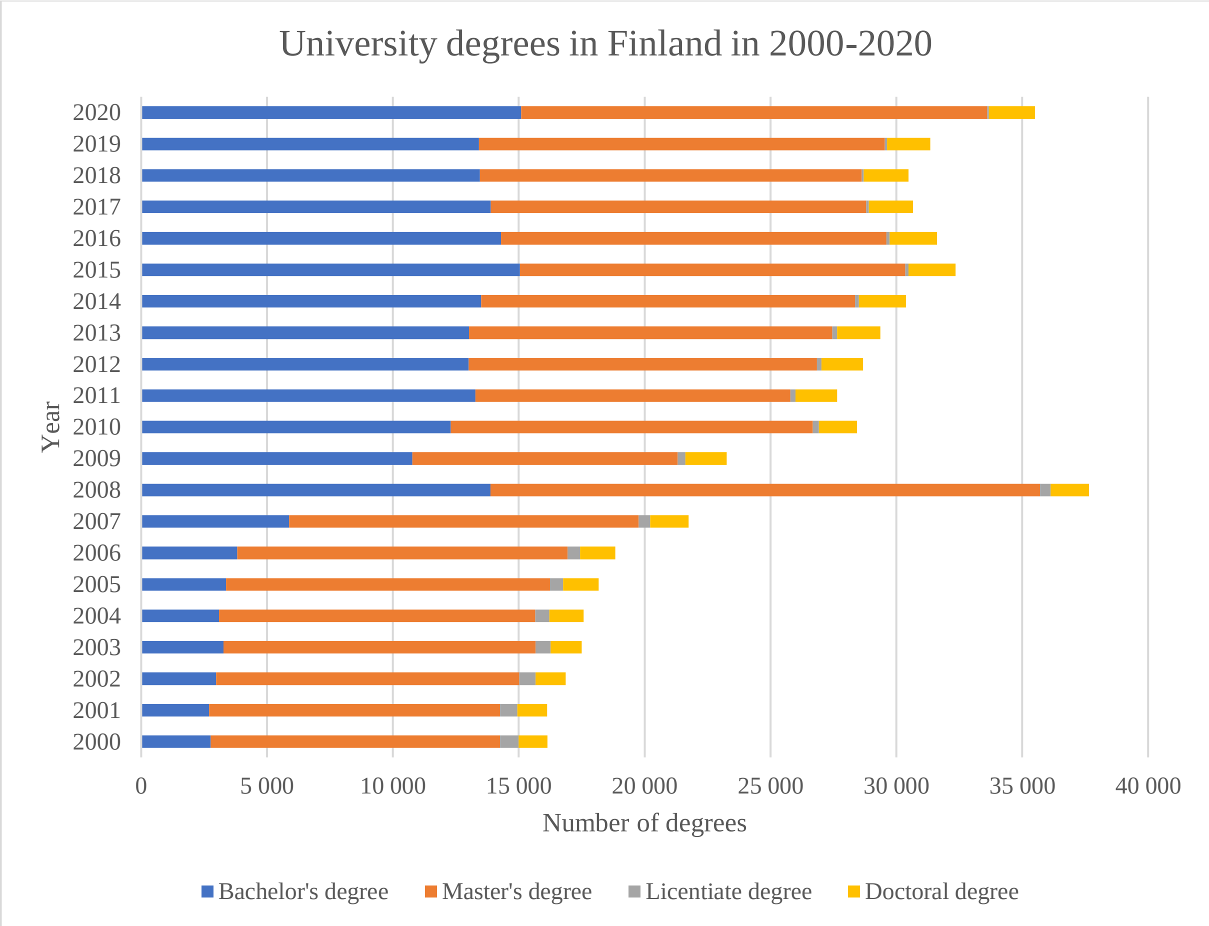


Figure 5. University degrees in Finland in 2000-2020 (Vipunen 2021)

In 2018, about 70 percent of higher educational level students studied for a lower-level degree and about 24 percent for a higher-level degree in Finland. The proportion of doctoral students was about six percent. About 60 percent of first-time university students have a high school diploma in the age of 18-20 years. The first-time students to polytechnics at age 18 to 20 years is 30 percent and the proportion of those having only a high school diploma is 21 percent. The median age of polytechnic graduates is 26 years, the median age of higher education graduates is 28 years, and the median age of doctoral graduates is 35 years. The share of women considers most of all graduates at university level. Exceptionally, the share of men is the majority in technology related field. (the OKM 2019)

4.2 University applicants and selected candidates

One of the problems of the Finnish higher education system is the prolonged transition of young people to the labour market with higher education degree. This is affected by the late transition to studies, studies passage, and long completion times. However, according to the study commissioned by the Ministry of Education and Culture, researchers from the Labour Institute for Economic Research (PT) and the VATT Institute for Economic Research (2021, 10), the speed of transition to higher education has slightly increased in 2020. The increase in the share of those accepted to studies was most pronounced in polytechnics but was also identified in the university sector.

The increase of share of people accepting the study place is more moderate. As highlighted in the VATT's report (2021, 10), the development of the share of applicants admitted to studies and receiving the study place does not necessarily mean that the transition to higher education would be significantly faster. In addition, the increase in 2020 was concentrated in older age groups rather than those just finished their secondary education. As emphasized in the report, in terms of student choice reform, more relevant is to concentrate on how the age structure of students entering higher education develop. The proportions of 19-year-olds and younger and 20-year-olds starting university studies also increased clearly in 2020, whereas the same time, the proportions of 21- and 22-year-olds declined. Thus, there are indications that the proportion of those finishing studies in the secondary degree among those who started their university studies increased in 2020, when the certificate-based admission to studies was introduced. (VATT Institute for Economic Research 2021, 13-14)

For the purpose of the simulation model, information on the distribution of study places among age groups in past years is important as with the model, one can investigate how the study place distribution and degree completion times affects to the number of young graduates. Based on the historical data obtained from Vipunen database, the youngest age group considered in the study (21 years and under) received averagely 67 percent of study places of all selected candidates in 2015-2020. As presented in the following Figure 6, the share was in 2020 highest in the University of Lappeenranta-Lahti (82%) and lowest in the University of the Arts (51%). In some universities (e.g. University of Jyväskylä, University of LUT, University of Oulu, Hanken School of Economics) the proportion is slightly decreased in 2020 compared to the year 2019.

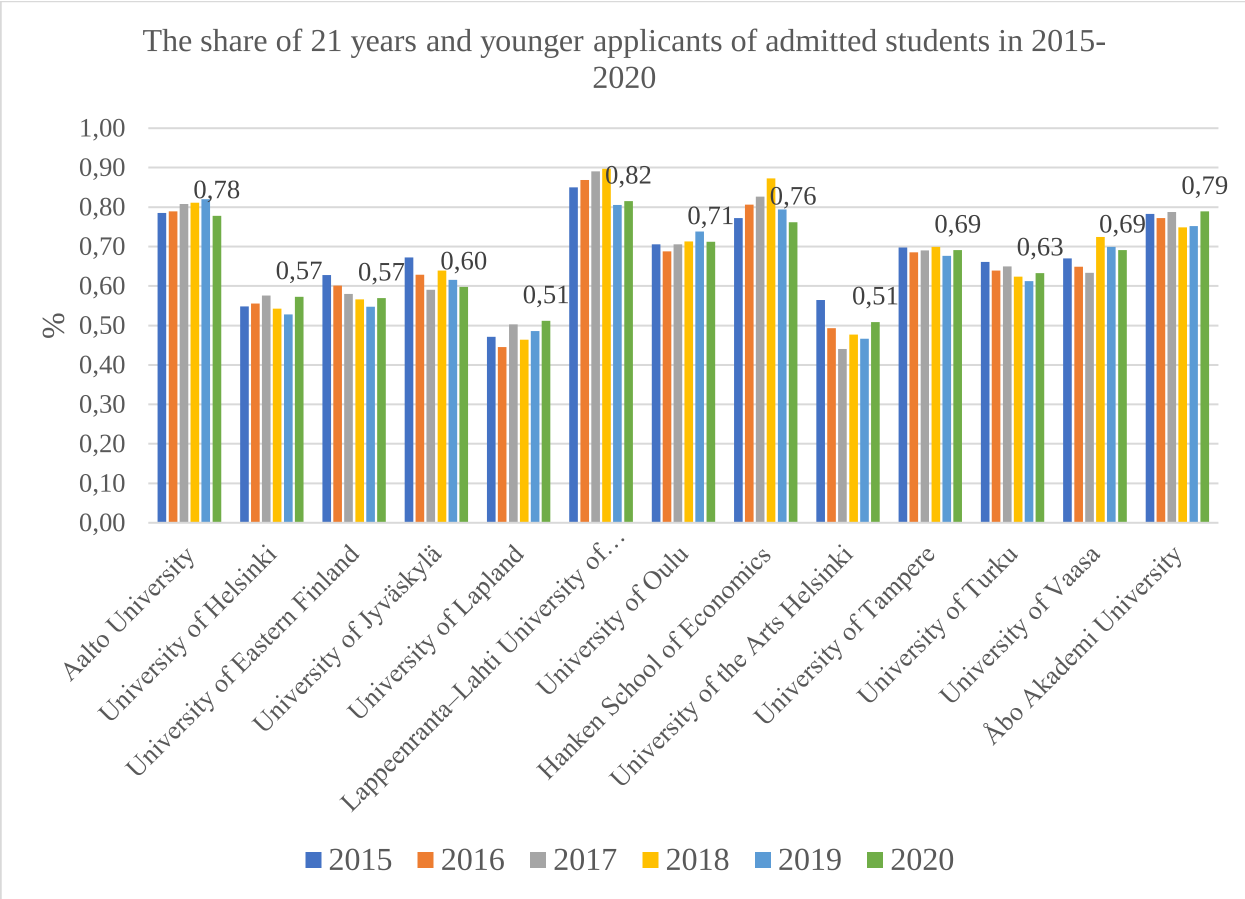


Figure 6. The Bachelor level study places distributed to the people of 21 years and under in 2015-2020 in Finnish universities (Vipunen 2021)

4.3 Progress of studies in Finnish Universities

Finns graduate from universities later than OECD average and less than half complete the degree in a target time (the OKM 2019). As highlighted in the OECD report (2020), there are concerns in OECD countries in general about the length of time tertiary students take to complete their studies. Therefore, policies have been developed to encourage students to graduate more efficiently with shorter study time, which produces highly educated people into the labour market at an earlier age.

In Finland, the degree is completed more often within the target time in the polytechnic sector than in universities, and there are also discipline-level differences in graduation times. Considering Bachelor’s degrees completed during 2015-2021, around 34 percent graduated within the target time of three years and around 66 percent graduated within four years.

Overall, less than half of university graduates completed a higher educational degree (Bachelor's or Master's) in a target time in all other fields except medicine. (OKM 2019) As Seuri and Vartiainen (2018, 11) denote, the differences in the speed of completion of studies among disciplines is not necessarily due to the effectiveness of education, as differences in student material and the labour market situation may be also part of the reason.

In the light of the historical data, the cumulative sum of graduates increases up to fifteen years considering the yearly classes in past. This suggest that universities are sensitive in granting additional time to complete studies, which again reflects to the problem of slow completion of higher education. Degree completion times can be also analysed regarding different age groups and universities, which is the method also in the model of this study, although study program-level differences are acknowledged to reflect to the university-level outcomes. With this scope, there seems to be significant differences in graduation times between universities and age groups, which is why statistical averages alone do not give a true image of the study progress of different student groups and yearly intakes. For example, when considering the age group division of the study, from the youngest age group (21 years and under at beginning their studies) starting their studies in 2015, averagely 40 percent completed the degree within the target time, with a standard deviation of ten percent and a median of 44 percent. At the University of Oulu, 48 percent of the age group starting their studies in 2015 graduated within the target time, whereas the percentage was 25 at the University of Helsinki and 22 at the Hanken School of Economics.

Considering the performance of 22–24-year-olds, taking all universities into account, the average of graduating within a target time in 2015 is around 40 percent similarly than with the previous case. The standard deviation is 12 percent indicating wider variability in outcomes. Interestingly, in some universities, e.g., University of Aalto and University of Lapland, this age group completed the degree averagely slower than the younger age group, whereas in most universities the study progress is more efficient considering people of 22-24 years. Lastly, considering people at age 25 years and over, approximately 56 percent completed the degree within the target time, with a variance of 14 percent and a median of 59 percent. Although the age group specification in the report is not balanced, the analysis suggests students aged 25 and over (at beginning of studies) completing their degree faster than younger students.

Based on the statistics obtained from Vipunen database, the study progress in Finnish universities have enhanced over the last decade from the perspective of increased number of credits earned by students. Seuri and Vartiainen (2018) discusses in their evaluation report the possible reasons for such improvement and the potential impact of the indicator set by the government in the funding model in the early 2010s, which rewards universities based on the students earning over 55 credits per year. From the following Figure 7, it is noticed that in averagely, the share of students earning over 55 credits per year has increased from 2010 to 2021 around 11 percent in all universities. In University of Oulu, Hanken School of Economics and University of Aalto, the increase in the share is around 15 to 17 percent and in University of Eastern Finland, University of Jyväskylä and University in Lapland the increase in share is around four to five percent.

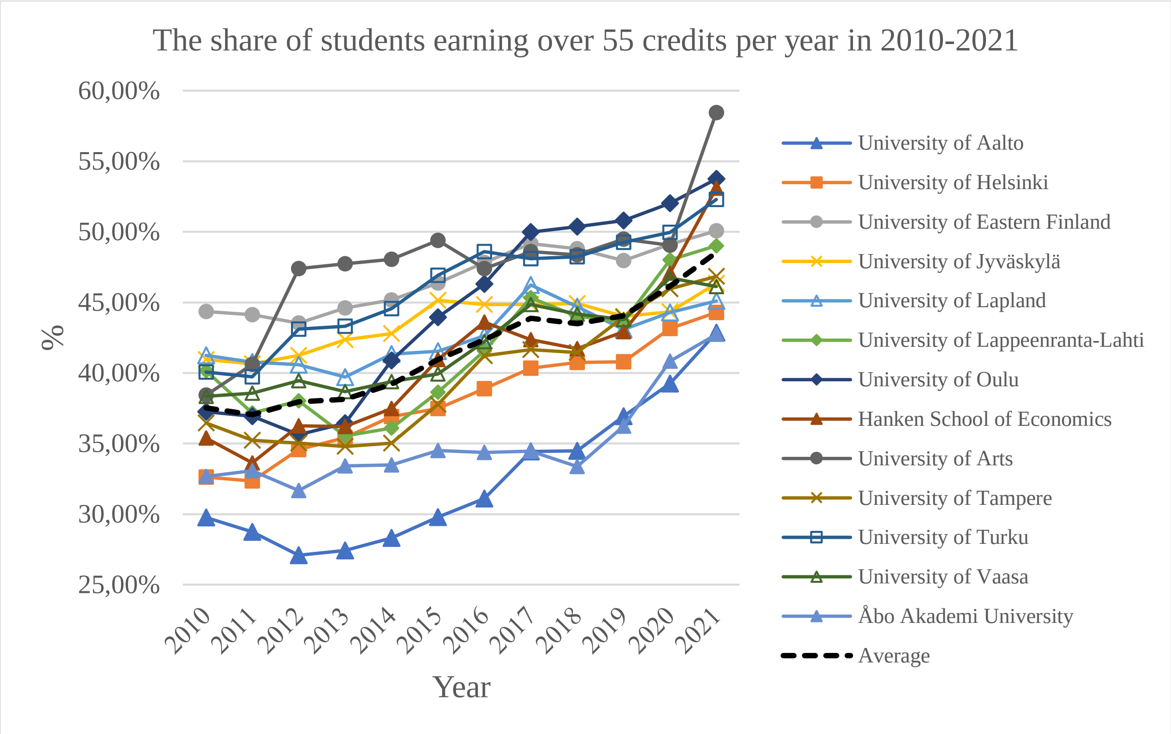


Figure 7. The share of students earning over 55 credits per year in 2010-2021 in Finnish universities (Vipunen 2021)

4.4 Impact of population projection on higher education in Finland

According to the statistics provided by the Official Statistics of Finland, although the size of the age group starting the higher education will not decrease significantly by 2030, the country's population appears to start declining after 2031 and the decrease in the size of the age group of 18-24 years will appear after the mid-2030s, as illustrated in the Figure 8. Accordingly, the decrease in size of the age group of 25-29 years will appear at the end of the 2030s. The forecast of the Statistics of Finland shows the demographic trend in circumstance that the past trend would remain unchanged for decades. (The Official Statistics of Finland 2019; The OKM 2019; Sitra 2020)

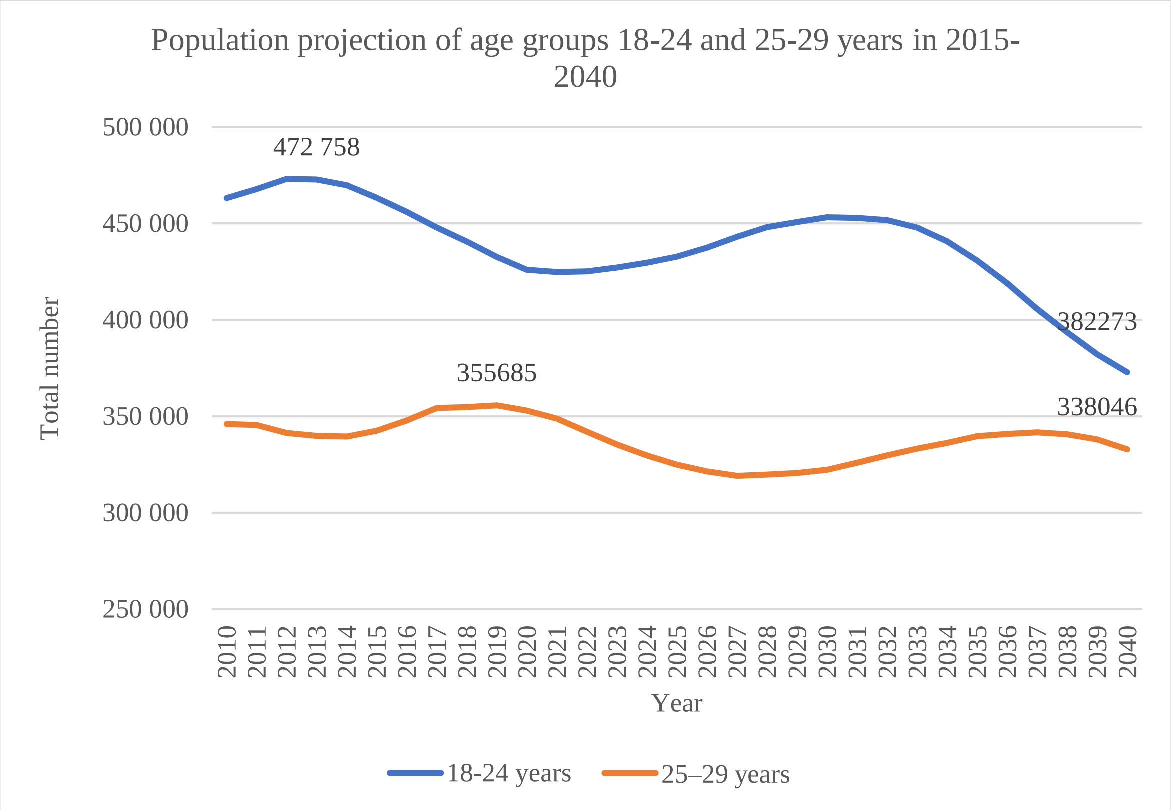
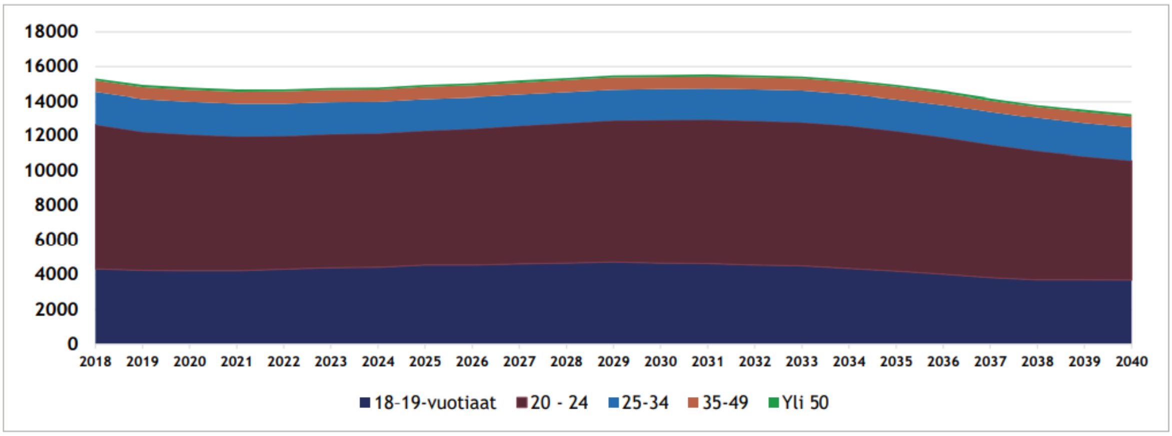


Figure 8. The population projection of people of age 18-29 years in 2019-2014 (The Official Statistics of Finland 2019)

The need for tertiary education has been anticipated in Sitra's study (2020), which provides a forecast for the number of new students in the future based on Statistics of Finland's regional and municipal population forecast for 2019–2040. In the study, it was assumed that the share of new students in the same age group in the same area remains the same throughout the forecasted period and the forecast of new students was then projected based on the regionalized number of new students in 2015-2018. The purpose of anticipating the need for education was not to assess exact number of new students, instead, the forecast sought to provide a basis for supporting educational policy assessments and decisions that will affect future numbers of new students. However, the Sitra's model for anticipating the need for education did not pay attention to foreign students or students applying abroad, which on the other hand, also influences to the need for higher education. Indeed, what matters in terms of higher education volumes is how large proportion of immigrants apply for higher education and how many people come to Finland for study purposes. (The OKM 2019)

Based on the Sitra's report (2020), the forecast of the number of new university applicants is slightly positive between 2018 and 2030. The growth is based on increase in the age group of young people over the same period, leading to an increase in the number of young people aged 18-24 and their proportion of all new students during the 2020s. The share of young adults (aged 25-34) and the number of new university students, on the other hand, will decrease as the age group of young adults decreases during the 2020s. It is noteworthy that any changes in the numbers and proportions of new students are well moderate at the national level during the 2020s. The Figure 9 illustrates new Bachelor's level students in age groups between 2018-2040 based on the Sitra's forecast. The changes in the age structure are reflected in the structure of new university students by reducing the share of 18–24-year-olds among new students and increasing the share of 25–49-year-olds. In 2040, just under four-fifths of new university students will be 18-24 years old. The changes in the age structure are moderate, as there are no significant changes in the number of other age groups. (Sitra 2020)

Kuva 54. Uudet yliopisto-opiskelijat (vain alempi korkeakoulututkinto) ikäryhmittäin 2018–2040 ennusteen perusmallin mukaan.



Lähde: Tilastokeskus, väestörakenne, väestöennuste; OPH Vipunen, yliopistokoulutus.

Figure 9. New Bachelor's students in 2018-2018 by age groups (Sitra 2020)

Sitra (2020) predicts that if the proportion of university applicants in the future is based on the size of the age groups, the number of young applicants will fall sharply from the 2030s onwards. According to the forecast, between 2018 and 2040, the number of new university students will decrease by 13.7 percent. The number of university students is declining likely more sharply than polytechnics students, as university sector consists of a larger proportion of students at young age. It is highlighted that even immigration could not compensate the decrease. The situation is the same for the number of new students among young age groups, if study places are allocated in proportion to the size of the age group. Thus, Sitra proposes that increasing the proportion of study places in relation to the age group would lead higher number of new students. Although study places at secondary education are not filled in all areas in future, in universities, a significant proportion of applicants are left out without a study place. According to Sitra (2020), maintaining study places at the current level, while the calculated need for education based on the population projection is declining, would not lead to empty study places, but to a larger proportion of new students in the age group.

In the discipline-level review, the highest number of new students in university undergraduate degrees is in the humanities and arts, as well as in business, administration and law. Fields of education with less than a thousand new students are the agricultural and forestry sectors as well as the health and welfare sectors. The number of new students is declining the most in degree programs of education and health and welfare. The number of new students in the technical field is growing the most and the second largest increase is in agriculture and forestry. Considering all fields, the total number of new students is expected to grow moderately by 1.3 percent in 2018-2030, however, in a long run, the change will turn to decline as in 2018-2040, the number of new Bachelor’s students decreases significantly considering all disciplines. In all fields, there are a total of 13,168 university undergraduate degrees new students according to the 2040 forecast. (Sitra 2020)

Sitra’s model (2020) to forecast higher education needs involves significant uncertainties as any forecast. One of the most meaningful uncertainty is related to Statistics Finland's population forecast. At the national level, population forecast uncertainties are related to future migration and the birth rate in the coming years. Another key uncertainty relates to the assumptions in the forecast for the number of new students, where the proportion of new students is assumed to remain the same in age groups throughout the period. The realization of the forecast as such can be considered very unlikely. In particular, an increase or decrease in the proportion of students entering different educational institutions can significantly increase the number of new students and later on the number of graduates.

4.5 The fund allocation model of Finnish universities

University funding in Finland has been based on performance since the establishment of performance agreements between the Ministry of Education and Culture of Finland and universities in 1994. Forming performance agreements is an interactive process between the ministry and the university sector. The ministry indicates goals and targets for the whole sector based on the development plan determined by the current elected government, whereas the institutions provide feedback on the guidelines, provide information on their strategic direction, and indicate their suggestions about what to be included in the agreements. (De Boer et al. 2015, 67; Pölönen et al. 2020, 7). The purpose of such mechanism in Finland, similarly than in other countries adapting the system is to boost the productivity and impact of the higher education institutions and increase the performance by enhancing efficiency, internationalisation, and quality. It also creates accountability and transparency, and allows the Ministry of Education and Culture to monitor and compare the performance between the higher education institutions in Finland (De Boer et al. 2015, 70; The OKM 2021; Pölönen et al. 2020, 7)

In Finland, the government core funding is the main source of funding for universities, accounting for approximately 60% of their income. Finland's Parliament decides the amount of university core funding allocated by the Ministry of Education and Culture in connection with annual Budget formulation. In addition to the core funding, universities receive financing from external funding sources, such as from the Academy of Finland, Business Finland, foundations, enterprises, the European Union, and other international sources. Based on strategic choices of each university, the institution's administration decides independently on the internal allocation of funding. (Adams 2020, 6; The OKM 2021)

Overall, Finland has made a significant investment in public funding for higher education and research by international standards. Public investment in colleges in them mission including research expenditure in relation to GDP are in Finland. In OECD comparison, the highest together with Norway and Austria. Larger than the Finnish level relative total investments can be found in countries where a significant part of university funding consists of private sector funding. (The OKM 2019)

The Finnish core funding model is formulated in the form of a four-year agreement, which advantage according to Adams (2020, 8) is that it offers flexibility to balance between continually changing short-term outcomes and long-term policy goals. In Finland, the previous agreement period covers years 2017-2020 whereas the current agreement considers 2021-2024. The level of funding is calculated by averaging the performance in the previous three years, which according to Galbraith (2010, 102) is usually a method for even out irregularities that enable gradual adjustment to changing circumstances. Hence, for example funding for publications in 2021 is based on the 2017-2019 publications, calculated in 2020. The ministry and universities negotiate the performance agreement including institution specific targets at the beginning of the agreement term, and the agreements are signed for universities by the chairperson of the board and the rector (Adams 2020, 6; De Boer et al. 2015, 69; The OKM 2021).

In the current university core funding model presented below in the Table 2, 42% of core funding is allocated to universities based on performance in education, whereas research performance account for 34% and other police considerations 24%. In particular, 19% of educational performance is based on Master's degrees and 11% on Bachelor's degrees. There are also coefficients based on graduation times, multiple similar degrees and fields of education. In Master's degrees, the funding is up to the agreed target. 14 % of research performance is based scientific publications, considering rating of publications in JUFOlevels with different coefficients (0.1-4). Part of the financing is allocated based universities' strategies, which are formulated together between the Ministry and the university. In addition, universities' national tasks and duties are taken into consideration in the central government funding for universities. In the Finnish funding model, the unit of assessment is always the university, not the department or a faculty (The OKM 2021; Pölönen et al. 2020, 62)

Table 2. Universities core funding from 2021 (The OKM 2021)

Category and the share	**Indicator**	**The share in the category**
Education: 42%	Bachelor's degrees and Master's degrees	30 %
		Master's degrees 19%, Bachelor's degrees 11%
	Continuous learning	5%
	Number of employed graduates and quality of employment	4%
		Number of employed graduates 2%, graduate tracking 2%
	Student feedback	3%
Research: 34%	PhD degrees	8%
	Scientific publications	14%
	Competitive research funding	12%
Other education and science policy considerations: 24%	Strategic development	15%
	National duties	9%

5. Data and methodology

The theoretical framework of the study is defined based on the literature review conducted as secondary research. The aim of the literature review was to uncover previously implemented projects related to the topic, so that the findings can be considered, and the best practices applied if possible. The methodology of the study adopts elements of action research meaning, that the research process integrates research and action in a series of flexible cycles. This cyclical, on-going process combining research with reflection in practice (see, Clark, Porath, Thiele & Jobe 2020, 9) usually involves the collection of data about the topic under investigation, analysis and interpretation of those data and its use and planning and introducing of action strategies. Since participative research is carried by a collaboration of the partnership of participants and researcher(s), the method shares similar principles with group model building approach discussed in the Chapter 2. In action research and GMB, the development of understanding is a unique kind, as different knowledge is collected from a team of individuals contributing own expertise, at the same time, enhancing both self-understanding and team learning (Scott 2019, 785; Birta & Arbez 2013, 34; Rouwette et al. 2009, 573; Somekh 2005, 7). In action research, the researcher is inside the actual situation, where the change and development are meant to be achieved (Somekh 2005, 6-8). During this project, meetings are arranged regularly with stakeholders to discuss about the progress of the modeling process and to tackle issues related to the functionality of the model and data gathering. Please see the project timeline from the Appendix 1.

System dynamics approach is applied for modeling the system of university degree structure respect to the fund allocation model defined by The OKM. The model is developed to forecast university performance in terms of the number of yearly graduates by age-groups and universities. Also, as the main outputs, the model provides predictions about the amount of fund each university receives based on the degree points, those are representing the educational performance measurement.

In the study, both qualitative and quantitative methods are applied to tackle the research problem. The model development process follows Sterman's (2002) methodology on building a System dynamic model. First, qualitative System dynamics methods are applied to identify key variables and their causalities illustrated in the causal loop diagram in a very high abstraction level, followed to the conversion of elements into the stock and flow diagram. The CLD, in particular, seeks to establish the dynamics between the society and the university system, involving population and economic factors of the country. Next, quantitative approach is adapted to enter the simulation phase, and qualitatively identified structures are used to build a simulation model that allows to analyse the dynamic behaviour of the variables. Experiments with real data are carried out as the validation phase to indicate that the model is representing the system sufficiently enough. By this, we ensure that the study goal will be achieved with a proper model. In the project, data preparation and analysis play an essential role before the actual experimentation phase. The analysis of historical data is essential in order to obtain for example the averaged proportions of degree completion times according to each university and age group in past as initial inputs, as well as to define initial values needed to set up Monte Carlo analysis and apply geometric Brownian motion. The model clarifications, modifications and elaborations are implemented during the process as flexible phases, and lastly, final analysis about the functionality of model and its results are implemented. The modeling and simulation process are presented in the Figure 10 through a process map diagram.

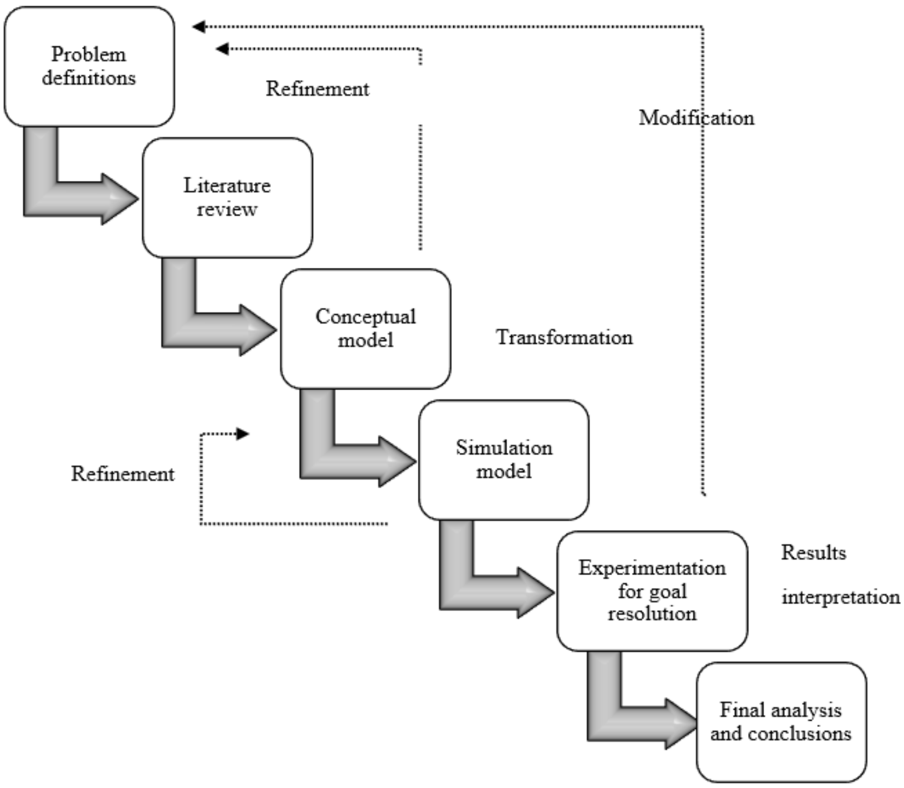


Figure 10. Modeling and simulation process (Sterman 2002)

5.1 Data collection

The model developed in the study is based on quantitative data on Finnish universities available in statistics released by Vipunen (2021) which is the education administration's reporting portal in Finland. Statistics of Vipunen are based on data and registers collected by Statistics Finland, the Ministry of Education and Culture and the Finnish National Agency for Education. The statistical service includes statistical and indicator information on education in various sectors, such as statistical information on the number of students in higher education, the completion rates of degrees, research conducted in higher education institutions, and the financial data on universities. In addition, information on population projection provided by the Official Statistics of Finland and analysis related analysis conducted by Sitra are utilized to increase understanding of age group development and the relationship with the development of highly educated population.

As the main purpose of the simulation model is to forecast the yearly number of graduates in each age groups and university, data related to the yearly number of study places and the study place distribution among age groups serves as the main inputs. The data concerning the number of new students in past is obtained from Vipunen database and during the simulation, new study places after the last statistical record are set to be constant following the last obtained value, allocated based on the university performance or manually by the modeler, discussed more in detail later in the report.

5.2 Variables of the model

The variables and their initial values involved in the System dynamics simulation model are presented in the Table 3. As seen from the table, several variables are having role as both, input and output variables. This simply means, that the output of one model part serves as an input to another part. Also, some of the parameter values are either obtained from Vipunen database or they are defined by the user. The user-defined parameters allow running sensitivity analysis by testing different values and their impacts to results under different conditions.

Table 3. Variables of the simulation model

Variable	Type	Data source/parameter value
The number of applicants admitted to studies (Bachelor's degree)	Input	Vipunen
The rate of students enrolled to studies in the starting year (%)	Input	Vipunen/User-defined parameter
The rate of FTE students	Input	Vipunen/User-defined parameter
The number of teaching staff	Input	Vipunen/User-defined parameter
The amount of OKM's base fund allocated to Bachelor's degrees	Input	1713823000*0.40*0.11
The rate of degree completion time 1-5	Input	Vipunen/User-defined parameter
The rate of degree completion time 6-8	Input	(Active new students *The rate of FTE students) *(1-The rate of FTE students)/3
Degree points coefficient 1	Input	1.5/User-defined parameter
Degree points coefficient 2	Input	1.3/User-defined parameter
Degree points coefficient 3	Input	1/User-defined parameter
Non-active new students	Output /Input	The number of applicants admitted to studies * (1 - The rate of students registered to studies in the starting year)
Active new students (including those who started their studies as non-active)	Output /Input	The number of applicants admitted to studies * The rate of students registered to studies in the starting year + Non-active new students
The number of degrees in the completion time 1	Output /Input	Active new students * The Degree completion time 1 (DELAY 1) * The rate of FTE students
The number of degrees in the completion time 2	Output /Input	Active new students * The Degree completion time 2 (DELAY 2) * The rate of FTE students
The number of degrees in the completion time 3-5	Output /Input	(Active new students * The Degree completion time 3 (DELAY 3) * The rate of FTE students) + (Active new students * The Degree completion time 4 (DELAY 4) * The rate of FTE students) ... + (Active new students * The Degree completion time 8 (DELAY 8))
The number of applicants admitted to studies-staff ratio (%)	Output	The number of applicants accepted to studies/The number of teaching staff
Total number of degrees	Output	The number of degrees in the completion time 1 + The number of degrees in the completion time 2 + The number of degrees in the completion time 3-5
Degree points based on the completion time 1 degrees	Output /Input	The number of degrees in the completion time 1 * Degree points coefficient 1
Degree points based on the completion time 2 degrees	Output /Input	The number of degrees in the completion time 2 * Degree points coefficient 2
Degree points based on the completion time 3-5 degrees	Output /Input	The number of degrees in the completion time 3-8 * Degree points coefficient 3
Total number of degree points per university	Output /Input	Degree points based on the completion time 1 degrees + Degree points based on the completion time 2 degrees + Degree points based on the completion time 3-8 degrees
Total number of degree points	Output /Input	Degree points of university 1 + degree points of university 2... + degree points of university 13
The amount of base fund for university	Output	Degree points of university x (moving average) /Total number of degree points* The amount of base fund allocated to Bachelor's degrees

The main inputs of the model are the number of new students, the rate of people enrolling to the studies in the first year being admitted to studies (%) and the rate of FTE students (%). Please see the numerical values for these inputs from Appendix 2. All inputs are considered by three age groups in each university. Age groups considered in the model are people at age 21 years and under, people at age 22 to 24 years, and people at age 25 years and over. It is decided to divide the age groups with an emphasis on groups aged under 30 years, as there is an interest to examine the graduation of the young population in particular, even the age groups with this specification are not balanced. Other model inputs are shares of different degree completion times (%), coefficients for degree points, and the number of teaching staff in terms of the person-year scene. The amount of core funding is also serving as the input for calculating the share of fund being allocated to universities. In this study, we set the amount of core funding to be constant for the sake of simplicity.

The knowledge about past degree completion times of students in age groups and universities is key in drawing future possible evolvements of study progresses in the simulation phase when geometric Brownian motion (GBM) is applied. The starting values of GBM realizations, discussed later in the report, are thus values calculated from statistics. The main idea is to draw future values presenting the share of students graduating in a target time as a continuum of the most recent statistical value. For the data analysis purposes, the proportions of degree completion times have been calculated from the statistics respect to the starting year of the studies, as discussed in the Chapter 4. This means, that instead of investigating cumulative share of degrees competed within a target time in a statistical year, in which several yearly classes are considered, the performance of an age group starting studies in the particular year is considered. This provides a more realistic picture of the development of graduation times on an annual basis, also being better suited to the functionality of the simulation model, in which at a time t, the model includes both the size of the age group at that time and their percentual shares of graduation times in future.

The main outputs of the model are the number of degrees completed at national level in total, and by age-groups and each university separately. Another key output is the amount of funding the university receives. In addition, the model produces an annual student-person-year ratio, which provides information on the distribution of teaching staff resources among new students. Although in this report, we do not focus on a more in-depth analysis of the latter output, it should be noted that the result can be used to draw conclusions whether the ratio of person-years to students is realistic if the number of yearly study places increases. This, especially from the institutional level perspective, might help in the resource allocation planning of personnel.

Many of the variable values, such as the number of new students, can be controlled by an Excel spreadsheet outside the Matlab, which serves as a user interface to run the simulation. The user interface is connected to Matlab in a way, that it allows changing also other parameter values simultaneously. This is considered to clarify the management of parameter values and increase understanding of the use of the model among other stakeholders. The user-friendly Excel interface is especially useful when the end user of the model is unfamiliar with the use of Matlab. An overview of the Excel user interface developed for this study is presented in the Appendix 3.

5.3 Model diagrams

The purpose of this chapter is to present the qualitative model, which helps recognizing causal relationships of the system and further guides to the formulation of the quantitative simulation model. First, the Finnish university system and its relationship with society is illustrated in a high abstraction level in the causal loop diagram in the Figure 11. The CLD helps to understand about the causalities between the national economy and the university system on a general level devoting the factors that contribute to the university financing and the number of graduates. The presented causal structure assists to address the outlined study problem and to understand the dynamics of the system, however, it is not designed to predict numerical values for variables for which purpose the quantitative simulation model is formed.

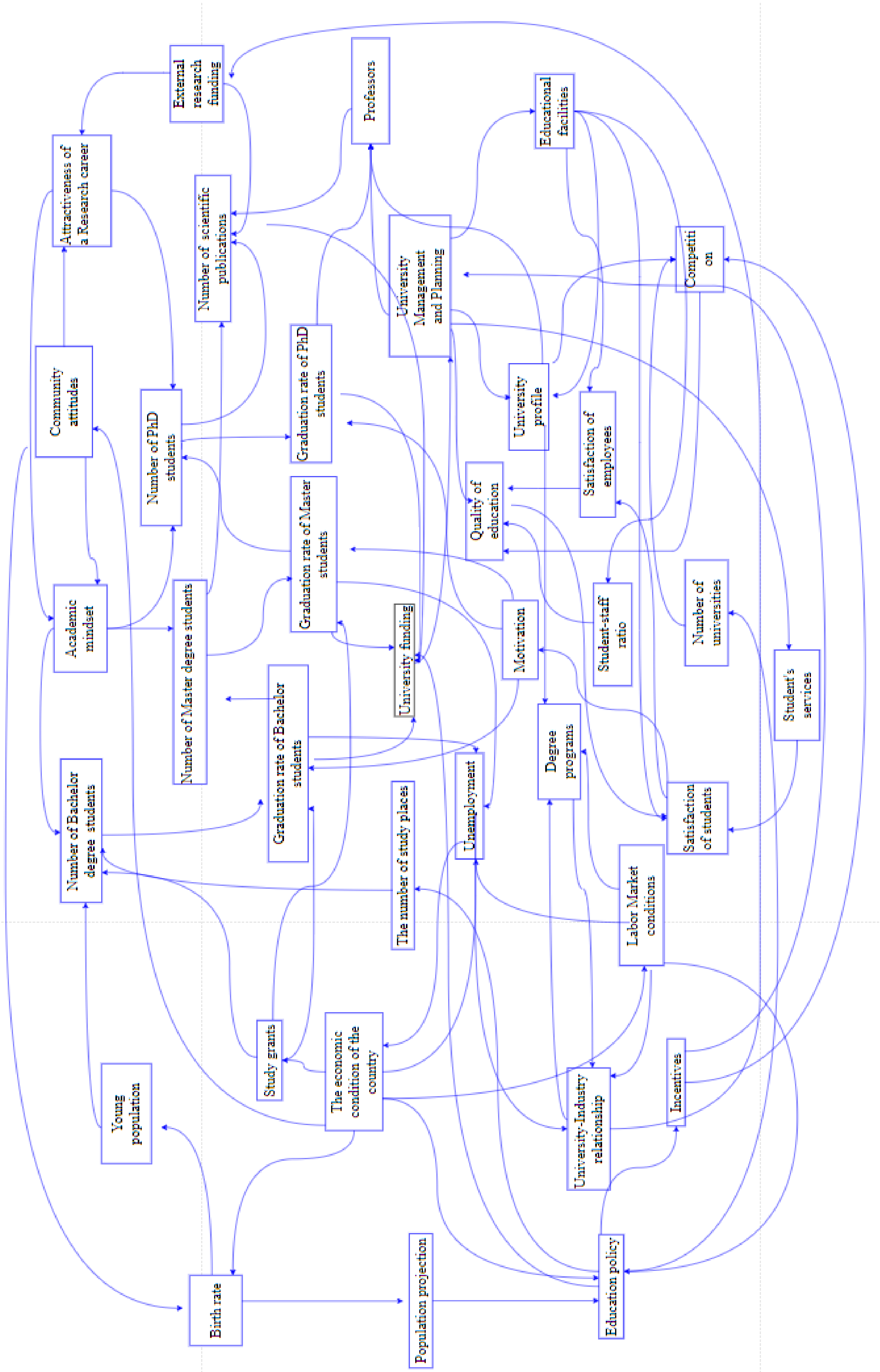


Figure 11. The causal loop diagram of dialogue between the Finnish university system and society

From additional diagrams presented in the Figure 12, one can identify the reinforcing loop (R1) involved in the above-described system. The amount of core funding the universities receive from the government affects the allocation and efficiency of resources through the internal planning of institutions. Better financial condition of the institution provides better possibilities to provide quality teaching, such as the number of teaching staff and modern teaching methods, which is believed to have a positive effect on the completion rate. Similarly, good economic condition of the university and modern teaching methods enhances its reputation and attracts the new professionals, which again enhance the reputation of the university. On the other hand, better degree completion rate of degrees together with positive feedback from students, increases the possibility to achieve larger share from the core funding as they are considered as indicators to measure the university performance in the funding model. Accordingly, better financial state and efficient study progresses might lead to possibilities to increase the number of yearly new students, again reflecting positively to possibilities to achieve higher number of graduates and core funding.

The balancing feedback loop B1 illustrated in the Figure 12 presents the impact of weakened labour market condition and increased unemployment rate to the higher education through economy and lower birth rate. From the viewpoint of the country's education policy in the balancing loop B2, we can consider that incentives set by the government increases the competition between universities, which has impact on the university profiling and to the number of applicants. This has impact on the number of completed degrees and again, to the university income. As discussed in the previous section, university with a strong profile attracts new applicants and succeeds in competition among other universities. This in turn has a positive effect on the income of better performing university, but similarly weaken the possibility of another institution to compete for core funding.

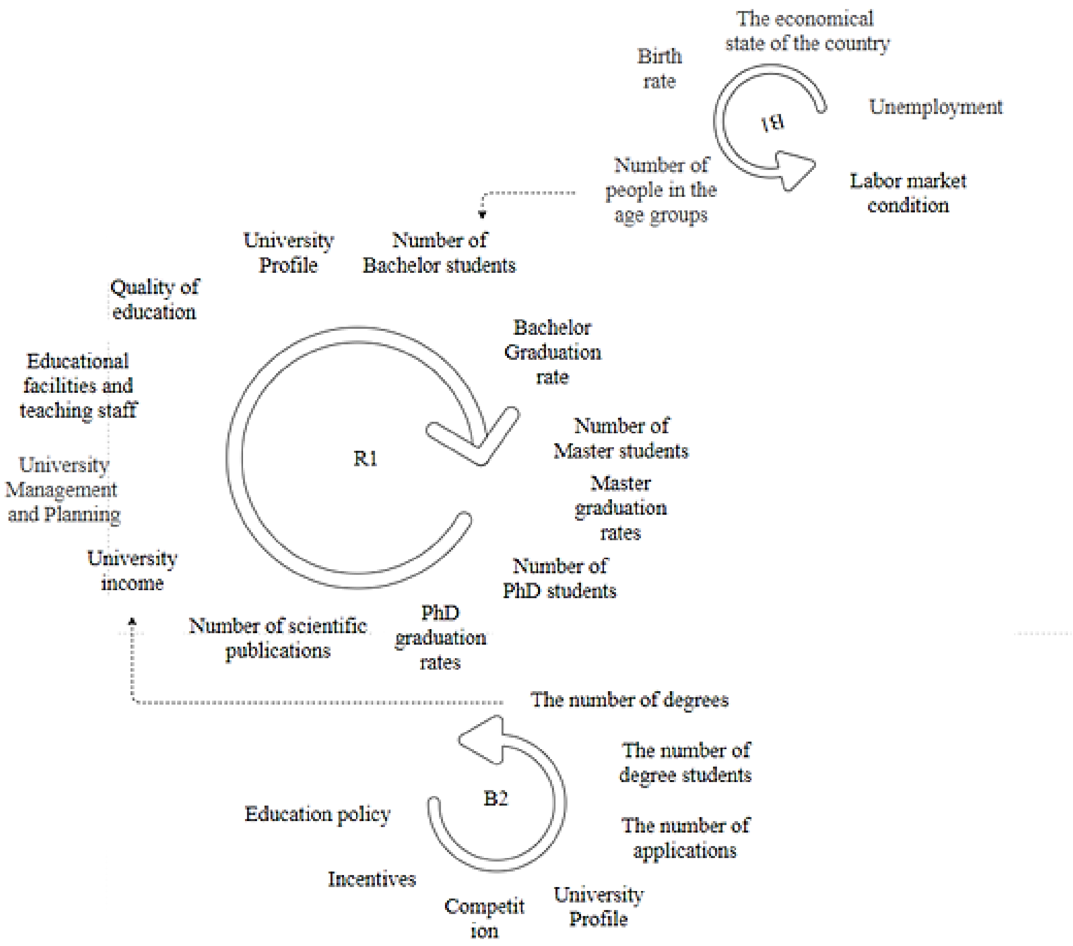


Figure 12. The generalized diagram of reinforcing and balancing loops of university financing and graduates

To capture the structure of systems in terms of stocks and flows, additional diagram of Figure 13 is developed. Stock can change only through a change in the inflow or outflow, those are each combination of the following individual variables: Young Population, Applicants admitted to Bachelor's studies, Bachelor's students, Bachelor's degrees, Drop-outs, and University income. Birth rate, Higher Education application rate, The Rate of Applicants accepting the study place, Degree completion rate, Drop-outs rate and Unemployed rate are examples of flows.

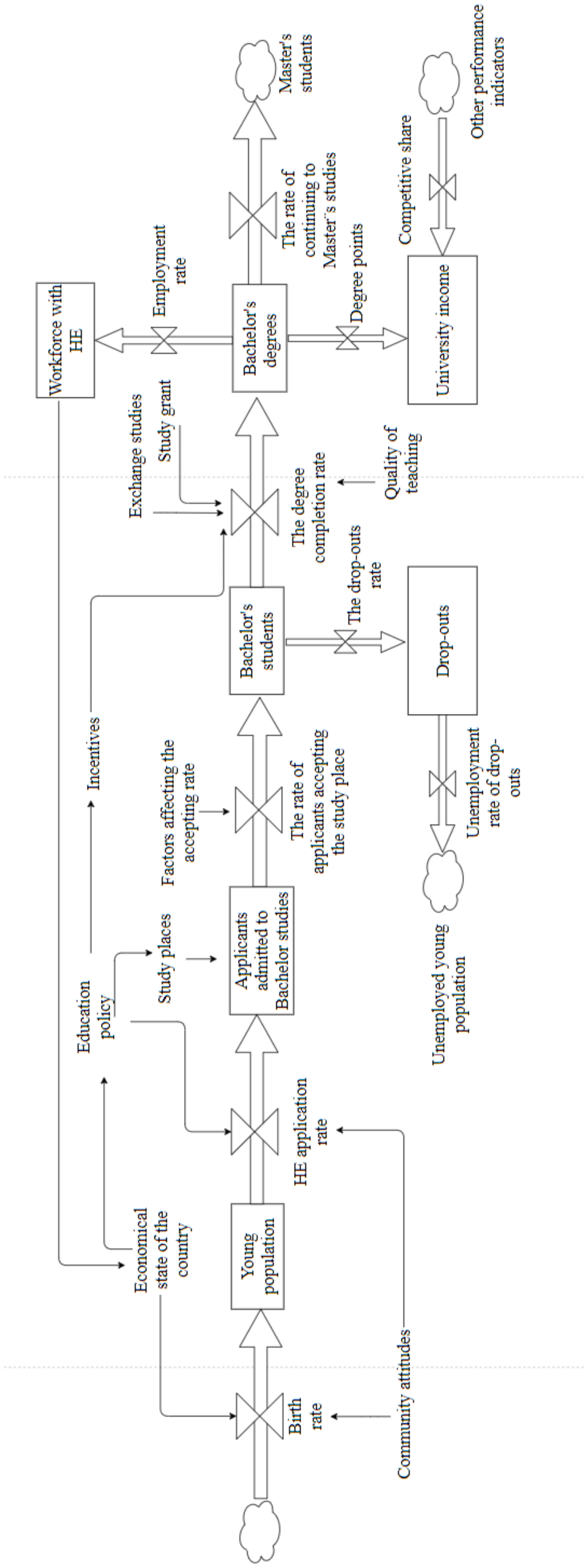


Figure 13. Stock and Flow diagram of the model

5.4 Simulation model

The modeling phase is implemented as a flexible process, whereby the model diagrams are reviewed during the simulating phase when necessary. During the modeling phase, discussions with the project stakeholders (The OKM side) are key in evaluating the functionality of the model and its possible improvements. The simulation model is constructed to demonstrate the degree system of universities by forecasting the number of completed degrees by age-groups. The model considers different graduation times in the calculation of degree points, that are the basis for calculating the fund allocated to each university. The yearly number of study places and the age structure based on which study places are distributed are having essential role affecting the modeling results. The model incorporates continuous-time Agent-based modeling features, as students starting their studies in each year progress through the system based on certain "rules", that in the model relate to enrolment rates, the proportion of degree completion times and the FTE rates.

To decrease the complexity of the simulation model and to keep the modeling phase within the study scope, following assumptions are made:

1. The number of people admitted to studies represents the overall demand. There is no distinction between foreign students and Finnish students. Also, alternative routes to higher education are not separated, such as the number of open university students admitted to degree studies.
2. The proportion of students not enrolled to studies in the same year being admitted is believed to be mainly due the Finnish military-service. The assumption is supported by statistics, as the proportion of unenrolled students is highest in male-dominated study programs among the youngest age group. This proportion of students is added to the model calculation after a one-year delay. The same procedure is followed for all age groups without considering other reasons affecting the enrolment status.
3. Students who have registered as absent during their studies after the starting year and are thus not included in the share FTE students will be added to the system after various time delays. This is because there is no exact information on how many academic years students in a particular yearly intake will be absent and what their actual graduation time will be after registered as a present again. It should be noted that taking into account

the proportion of FTE students, the accuracy of the model is improved when tested with historical data.

4. The model assumes that students will graduate within ten years, although based on historical data, the number of degrees completed by those who have started their studies in a particular year increases cumulatively up to fifteen years. As each delay component involved to the model require its own data analysis about the averaged proportion of people going to graduate later than the target time, it is decided to observe in the model only degrees that are expected to be completed within ten years from the beginning of the study. This means, that the proportion of those graduating in ten years includes also those graduating afterward. This is stated to adjust with sufficient accuracy the effect of graduation time on the number of degrees.

5. The simulation model considers university-level performance without separating study programmes with respect to the model boundaries and due the lack of sufficient data to cover smaller study program having limited yearly intake.

6. Followingly, in the base fund calculations, degree points are calculated only based on the degree completion time and the number of graduates, without taking account study program-based scoring.

The System dynamic simulation model consists of subsystems representing each university separately. The structure of one separate subsystem in the Matlab Simulink workspace is presented in the Figure 14, whereas the overall high-level system structure is illustrated in the Appendix 4. The progress of the system is read from left to right. In each subsystem, there are three entries for new admitted students separated to age groups. These numbers reflect the number of yearly study places. There are two options to control the input of the number of new students. First, the variable values can be obtained from a spreadsheet formatted user-interface outside the Matlab workspace. This option allows manually inputting values of new study places without no relation to the university’s past performance.

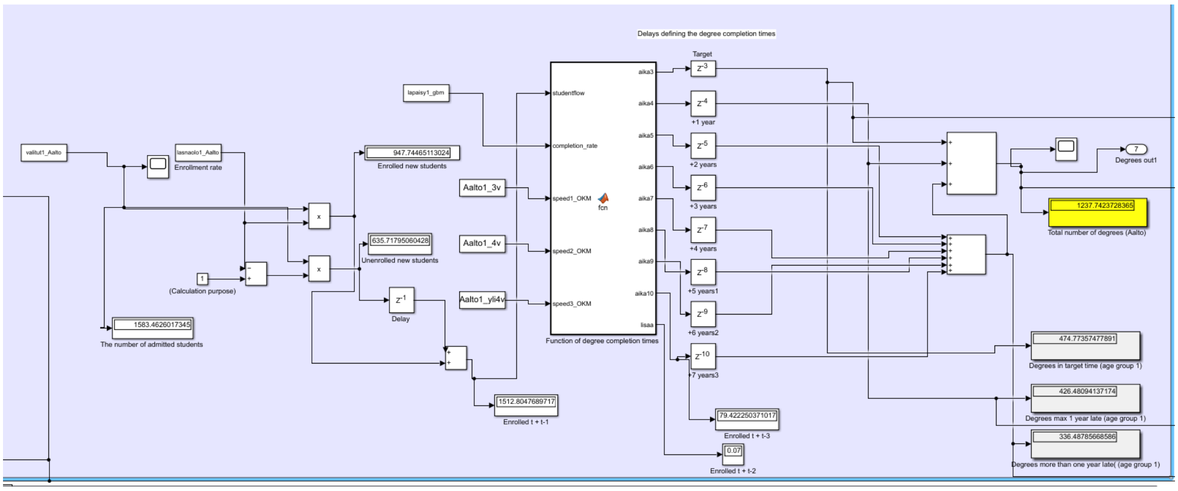


Figure 14. Subsystem of the simulation model representing one university performance

The second option to control the number of admitted students, also utilized in the simulations implemented and presented in the report, is through the feedback loop constructed to describe dynamically the relationship of university productivity and the number of study places. This functionality is based on the assumption of the reinforcing loop that indicates that the improved performance of a university has a positive impact to its possibilities compete for core funding, and further its possibilities of introducing more study places. As it is assumed that those universities that enhance the performance of studies will provide more study places in future, universities that increase their yearly number of target time graduates are having increased number of new admitted students in the following year(s). Thus, when the study progress in a university becomes more efficient, the number of yearly graduates will obviously increase. As such, the model compares two last values of target time graduates during each simulation time point t and calculates whether the value is increasing. The modeller can set the initial parameter values as the rule in the function algorithm which adjust the study places, for example how high the increase of the number of target time graduates needs to be in order that the performance is considered to be improved and also, what is the coefficient for the increase in the yearly number of study places for each age group. Technically, this functionality implemented in the model involves so-called “if-else”-condition.

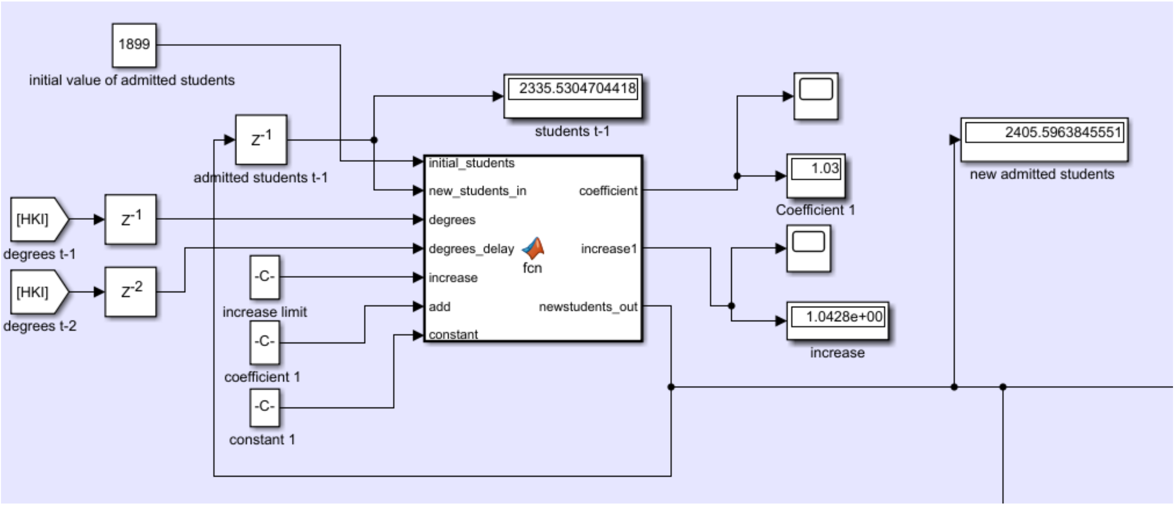


Figure 15. Additional part of the subsystem for calculating the number of admitted students based on the previous year's performance as a feedback loop

The entity of new students representing the yearly class in time point t, starts to progress in the system through time, each time point representing a year. First, the student entity entering the system is divided based on the rate, that defines the proportion of yearly class being enrolled to the studies immediately or later. It is known that a certain share of those not enrolling to studies in the academic year being admitted to studies considers mostly people liable for military service. In the model, this is considered so that the proportion of those not starting their studies at the initial time point, enrol to studies with a one-year delay. The number of people admitted and enrolled to the studies in the same year of admission in time point t, added with the number of students not enrolled to studies in the last year in time point t-1, regulate the number of active students, who begin to complete the degree in the particular time point. Later on, student entities are again multiplied with the coefficient indicating the rate of FTE students, which means students that are actively contributing to studies in a particular academic year. Those not considered as active students in time point t are added back to the process later in the system.

Next, student entities (groups) are divided to follow different paths to the graduation based on the delay length describing the time it takes to each group to complete studies maximum of ten possible study years. This means that only a certain percentage of students complete the degree within the target time of three years, and some finish their studies varying from one to more additional years. The proportion of those using ten years to complete studies is obviously lower compared to those finishing studies faster, following again statistical probability distributions. Since the model has in total of ten delays describing the maximum time spent completing a degree, the simulation must be initialized also with the values of ten previous years before the time point from which the results are to be viewed, so that the outcomes cover all possible years each yearly intake might use in completing a degree. For example, if the results of the model are considered from 2020 onwards, input values for the required variables from 2010 onwards are needed. Overall, such delay functions create dynamics in the model in the sense that the number of degrees completed in the coming years depend on both the degrees completed in the target time and the number of students who needed several additional years to finish their studies. Also, simultaneous changes in the parameter values regarding the number of admitted students, the enrolment rate, and the degree completion rates of different age groups and universities also appear in the model results respect to the delays, all of these having combined effect on the modeling outcomes. Described delay functions mimic the real-world university degree system.

Next, the calculation of the share of core funding the university achieves is based on the degree points, those calculation follows The OKM's core funding model calculation, which considers the share of graduates in the target completion time and thereafter. In the current funding model, degrees completed in the target time of three years from the start of the studies are multiplied by the coefficient value of 1.5. The graduates of maximum of one year late from the target time are multiplied by 1.3, whereas graduates who are late in the target period more than one additional year receive the coefficient value of 1. Thus, the graduation time has a significant impact on the degree points and the amount of funding the university receives. Since The OKM uses the average of three previous years in degree points in the financial calculation for the next period, the model includes a moving average component in the calculation of degree points.

The last part of the model emphasizes the competition between universities for funding. The output from the averaged degree points calculation serves as an input to the core funding calculation. Degree points produced by all the universities are added together and the share of each university in relation to the whole number corresponds to share of the amount of funding. Thus, university with the highest number of degree points achieves the highest share of funding. To be mentioned, the possible high number of degree points university achieves might be due two reasons. First, the overall high volume of students and thus the high number of graduates despite the efficiency of study progresses might lead to higher number of degree points. Alternatively, university with less volume in terms of the number of students might still achieve relatively large share of core funding if it achieves degree points with the higher coefficient due the efficient study progresses and large proportion of students graduating in a target time.

To validate the model functionality, the prototype model was tested during the model development phase to conclude, that it can replicate historical data. To be mentioned, some limits in data availability were acknowledged that affects to the model validation using historical data, as for example, to test the results of the model with realized data, data from 2000-2010 are needed both in terms of number of new students, FTE rates and graduation times, to get the full results in terms of number of graduates for 2010-2020 due to internal time delays in the model. Nevertheless, these limitations did not completely preclude model validation utilizing historical realizations and it could be concluded that the model is well capable of replicating real-world connections and it works technically without errors. The Figure 16 illustrates the real number of Bachelor’s level degrees completed in 2017-2020 and simulation model results obtained during the model validation phase.

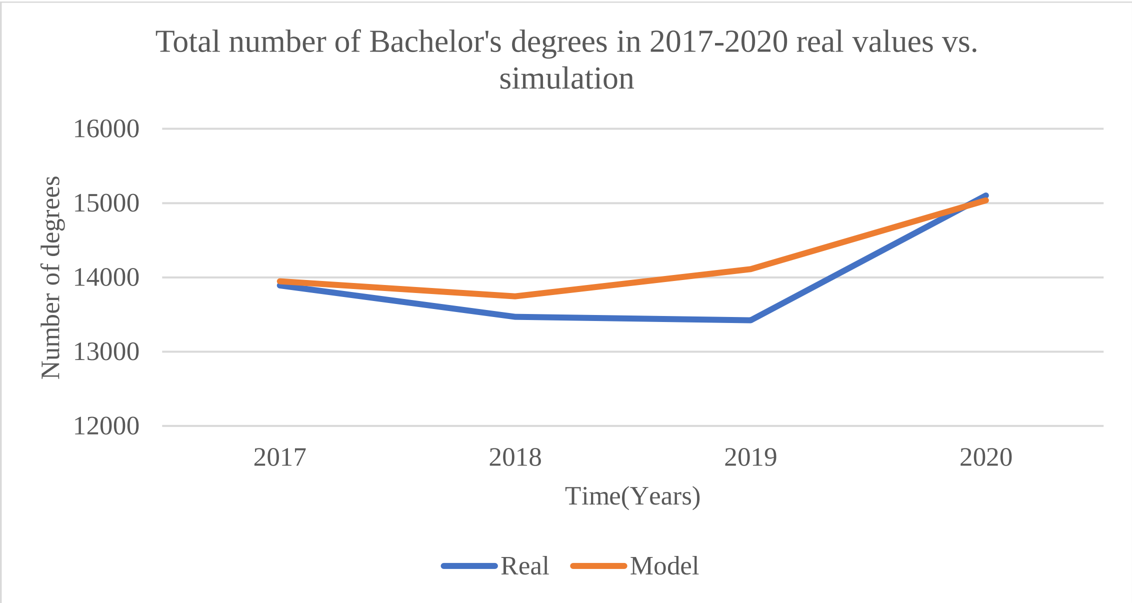


Figure 16. The number of Bachelor’s degrees in 2017-2020 (real values vs. simulation)

5.5 Simulation scenarios

As discussed in the Chapter 2.6., numerical sensitivity analysis can be implemented by testing the model behaviour under varying conditions and then observing results for example, in terms of best and worst cases. More comprehensively, Monte Carlo simulation allows obtaining insights into several alternative futures respect to specified probability distribution of model parameters simultaneously. In this report, the interest is to run the simulation model using Monte Carlo approach due its powerful way to explore, in which range results might vary in different circumstances. The code for running the Monte Carlo simulation is developed and geometric Brownian motion is applied as mathematical framework to draw the paths of parameter values presenting the share of future target time graduates using random numbers generated from the probability distribution, which in turn, is based on the statistical analysis implemented to the historical data.

The aim of sensitivity analysis conducted in this report is to demonstrate the model usage in terms of predicting the number of yearly graduates. Monte Carlo analysis is implemented to test, what are possible future outcomes in the number of graduates especially among the youngest age group under different conditions, that in this study, refers to the varying number of study places, the allocation of study places among age groups, and degree completion times. Further on, when referring to the youngest age group, it means people at age 21 or under at the beginning of studies, instead of at time of graduation.

Three different simulation rounds are conducted with an assumption that degree completion in the target time will be given more emphasis in the OKM funding model. The first simulation consists of three separate parts, the results of which support each other's interpretation. As discussed earlier in the report, because assessing the overall impact of indicators and policy change on university performance is not straightforward, in this report, the actual incentive does not play the key role. Moreover, the emphasis is on illustrating the possibilities of the simulation model to address the impact of a future policy change under alternative scenarios if there is previous evidence or a hypothesis of the likely impact of indicator. The main assumptions of the simulation rounds are summarized in the Table 4.

Table 4. The main assumptions of the simulation rounds

Assumptions	Simulation 1 a: equal policy responds	Simulation 1b: equal policy responds and fixed FTE-rate	Simulation 1c: no improvement	Simulation 2: diverged policy responds	Simulation 3: diverged policy responds and fixed study place allocation
Respond to policy change	Universities respond equally to education policy change	As in 1a.	No respond.	Universities respond unequally to education policy change	Universities respond unequally to education policy change
Study progress	Equal effect. The yearly increase in target time graduates is around 3 % in each university considering the youngest age group	As in 1a.	No improvement since the last statistical year 2021.	Unequal effect. The yearly increase in target time graduates varies from 0.5 to 3 % in universities considering the youngest age group	Unequal effect. The yearly increase in target time graduates varies from 0.5 to 3 % in universities considering the youngest age group
The FTE rate	Historical values.	Fixed to 90 % considering the youngest age group.	Historical values.	Fixed to 90 % considering the youngest age group in universities most sensitive to enhance study progresses. Otherwise historical values.	Fixed to 90 % considering the youngest age group in universities most sensitive to enhance study progresses. Otherwise historical values.
Study places and their allocation	No increase in the number of study places after the last statistical record. Study places are distributed based on historical allocation.	As in 1a.	As in 1a.	More study places are introduced in universities that can enhance their performance. Study places are distributed based on historical allocation.	More study places are introduced in universities that can enhance their performance. Fixed allocation. Increased share (75 %) of study places are allocated to the youngest age group and the rest are evenly distributed among the other two age groups

As the research is based on the desire to accelerate the graduation of young people in particular, in the report we focus on simulating the change in study progresses of the youngest age group with the assumption, that the performance of other age groups remain constant following the last statistical records (2020/2021). It should be noted that other age groups than the youngest one are completing their degree already averagely faster in terms of target time graduates. The assumptions of three different simulations are introduced more in detail in the next paragraphs.

Simulation 1 a: equal policy responds

In the first simulation it is assumed, that universities respond equally to policy change and the proportion of students completing studies in the target time will start increasing after the year 2020 considering the youngest age group, meaning people at age 21 and under at the beginning of studies. The yearly number of new admitted students remains constant throughout the simulation period from the year 2021 (see again, Appendix 2).

The equation following geometric Brownian motion used in the Monte Carlo simulation is obtained in Matlab and initial starting value (the last statistical value of the share of students graduating in a target time), standard deviation (volatility) and trend used to draw the GBM processes are inserted. We draw 1000 possible paths describing how the proportion of degree completed in the target time could evolve in future among people at age 21 years or under as a continuum of the latest value calculated from statistics. Proportion for graduation time maximum one year late and thereafter, are calculated based on the values obtained from the GBM to the proportion for graduation times in a target time. For the first simulation, the GBM realizations are obtained considering trend value of 3 percent, that controls that the proportion of graduates in the target time increases in all universities from the initial values accordingly. Likewise, the volatility of all realizations is the same, in this case, one percent. Example of GBM realizations is illustrated in the Figure 17, which presents the alternative paths of proportion of the youngest age group graduating in a target time in University of Vaasa. Averaged realizations of all universities are presented in the Appendix 5. The average increase in target time graduates between years 2020 and 2040 is around 32 percent.

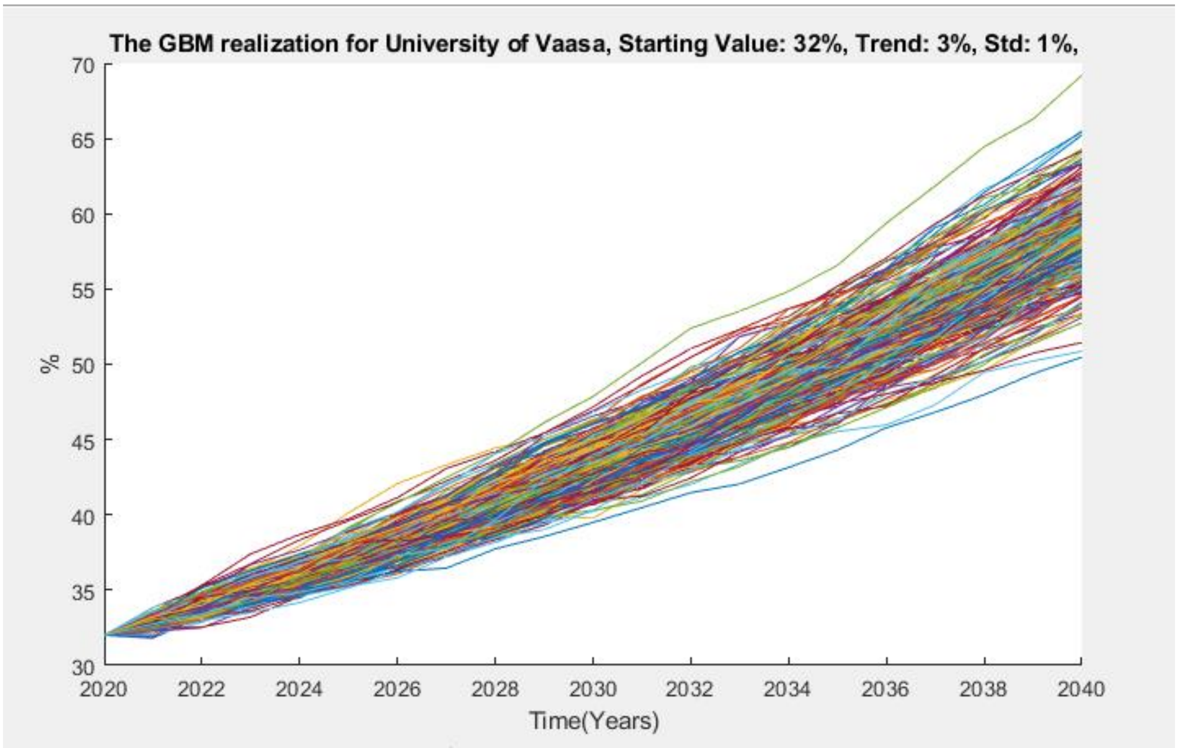


Figure 17. The GBM realization of alternative paths for the share of graduates in target time in University of Vaasa in 2020-2040 (people 21 years and under)

Simulation 1b: equal policy responds and fixed FTE rate

To achieve better understanding about the pure impact of enhanced study progresses on number of graduates, for a purpose of results comparison, we will run additional simulation round belonging to the first scheme, in which the rate of FTE students considering the youngest age group is fixed up to 90 percent from average of 83 percent. This provides an idea of how, for example the decrease in the number of intermediate years and non-active students affects the results. We can consider this kind of situation as the most optimistic one. The GBM realizations used in the simulation 1a are applied also in this case.

Simulation 1c: no improvement

Followingly, another additional simulation run is conducted for showing results in case of no improvement in study progression, which stands for the most pessimistic case.

Simulation 2: divergent policy responds

In the second simulation, we assume that universities will react differently to the possible policy change. Also, the model component, in which the coded rule regulates the increase of study places based on the university performance is now applied. The algorithm in the function works in a way that if the university improves its number of yearly target time graduates by two percent considering past recent years results, the number of new admitted students increases by three percent. Alternatively, with no such improvement, the number of new study places increases by one percent. The study place allocation follows the recent years distribution (see again, Chapter 4.2).

As the productivity of university is based on different sensitivity of universities to improve their performance after a policy change, some basic assumptions need to be introduced. At this point it should be again noted, that as the real impact of incentives and the sensitivity of universities to change are challenging to measure, as a starting point for this scenario, we use a study conducted by the Finnish Union of University Professors (2021) on the internal funding models of universities, which shows which universities follow the national funding model of the OKM more closely. We assume that those universities that have internal incentives for educational productivity more than 50 percent are likely more sensitive to the externally driven incentive. However, in this study, we do not delve into the methods universities might try to enhance the faster graduation, which may relate to, for example, student support services and issues related to the quality of teaching, among other things. Institutions considered more sensitive to enhance their performance consists of University of Lappeenranta-Lahti, University of Eastern Finland, University of Jyväskylä, University of Lapland, University of Oulu, University of Turku and Åbo Akademi University. Please see the summarization of internal funding models of Finnish universities from the Appendix 6. In this simulation round, we also fix the rate of FTE students with listed universities in a way, that in each university the yearly rate is increased up to 90 percent from the average value of around 83 percent of the year 2021. Higher FTE rate again means that a larger proportion of students attend to studies each year.

Figure 18 presents averaged results of 1000 realizations of the alternative evolutions of proportion of degrees completed in a target time among the youngest age group in several Finnish universities based on the second simulation. The numerical values of the averaged realizations in all universities during 2020-2040 are presented in Appendix 7. For GBM initialization, different values for trend of increase varying from 0.5 percent up to three percent were used to draw the proportions of target time graduates in universities respect to their likely response to the policy change. To be mentioned, the difference between University of Helsinki to other universities in terms of enhancing the share of target time graduates is identified and provides interesting starting point to examine simulation results, as the university is relatively large in its size and produces high number of degrees per year, also achieving larger share of the core funding.

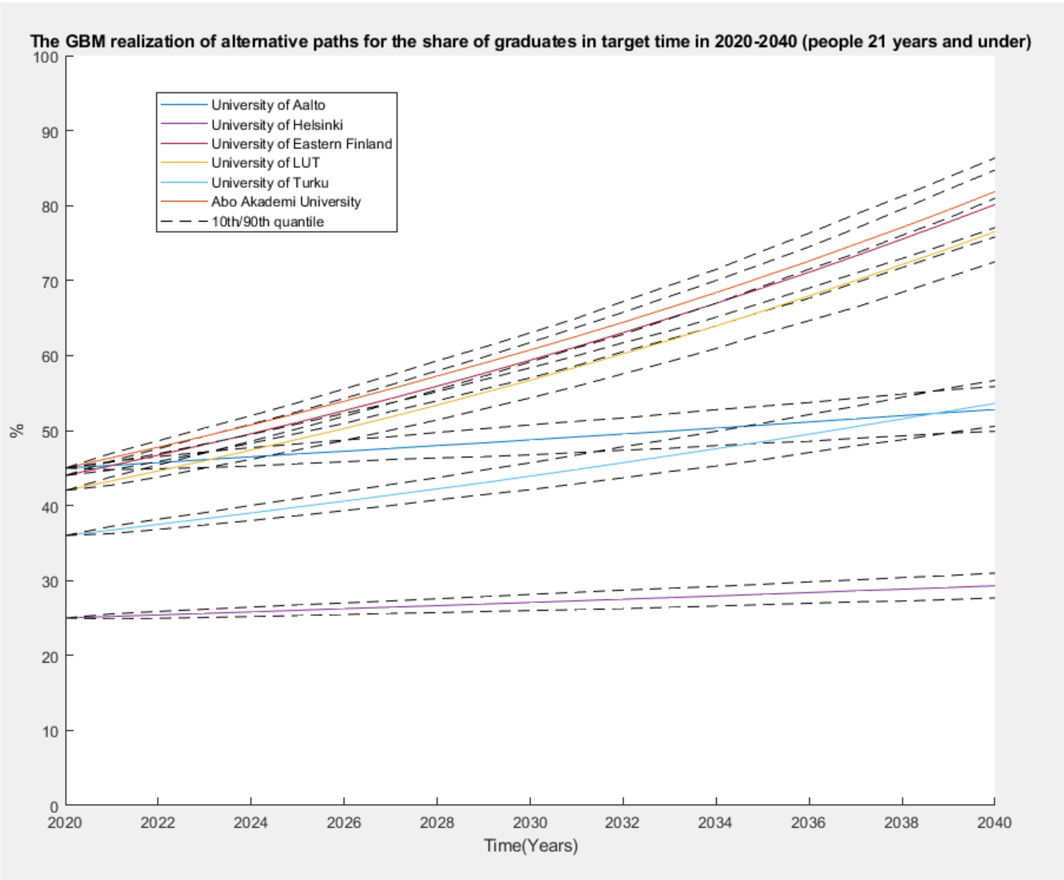


Figure 18. The GBM realization of alternative paths for the share of graduates in target time in 2020-2040 (21 years and under). Solid lines represent averaged realizations for several universities and dashed lines correspond to 10^{th} and 90^{th} quantiles

Simulation 3: divergent policy responds and fixed study place allocation

Lastly, in the third simulation, we allocate study places by 75 percent to the youngest age group in all universities and the rest of the places are distributed equally to other two age groups. As such, in this simulation, new students will consist more first-time university students who have just completed a secondary degree, having no previous higher education degree. Otherwise, the simulation assumptions are similar than in the simulation 2. The GBM realizations produced for the simulation 2 are also applied in this case.

It should be mentioned, that in this report we do not include a possible scenario that the proportion of graduates in a target time would start to drop unexpectedly oppositely to the aim of incentive set to boost the graduation time. A scenario like this would be quite unrealistic in real life, but from the viewpoint of the simulation model, it could be also possible to test such conditions so that the GBM equation produces alternatives for the development to go in either a positive or negative directions.

5.6 Results

The model is simulated, and results are obtained from the Matlab simulation software. The aim of the simulation 1a (equal policy responds) is to provide insight into the effect of enhanced study progress under the conditions, that the yearly number of new study places remains constant after the year 2021, whereas the proportion of youngest age group completing degree in a target time increases year by year. The upper plot of Figure 19 represents the total number of yearly graduates of all universities respect to the condition in which the proportion of the youngest age group completing studies in a target time increases averagely by around 30 percent between the years 2020 and 2040 in all universities. The plot below illustrates the results concerning the youngest age group in particular. The GBM realizations produced to obtain alternative paths of development of graduates within a target time reflects to the results in a way that instead of only one possible outcome, several slightly differing results are achieved, illustrated as coloured solid lines in the figure. The upper dashed black line represents averaged result of the simulation 1b, in which in addition to increased proportion of target time graduates based on the GBM realizations, the yearly share of FTE students increases from the current average of 82 percent to 90 percent considering the youngest age group in all universities. The dashed red line represents the outcome of simulation 1c, in which the study completion time is not enhanced after the recorded year of 2020.

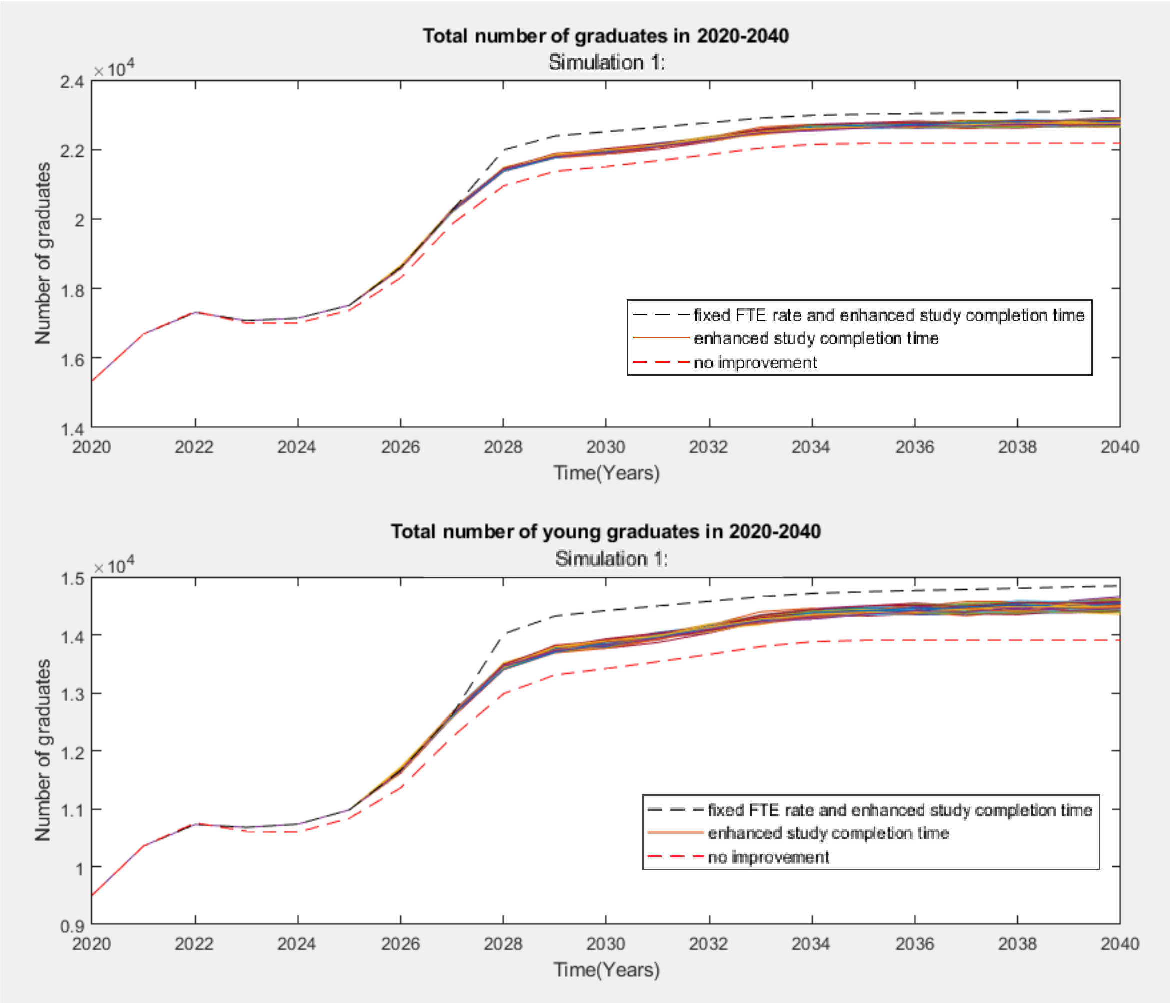


Figure 19. Total number of Bachelor level graduates in Finnish universities in 2020-2040 based on the simulation 1 a-c results. Solid lines represent 1a results, black dashed line averaged 1b results, and red dashed line averaged 1c results.

As identified from the visualization, there is a more significant increase in the number of yearly graduates between years 2020 and 2034, which is explained by the real statistical values used in the simulation to define the number of study places between years 2010 and 2021. As the simulation uses ten delay functions to describe the full possible study time of one yearly intake, increase or decrease in the parameter values, such as the number of yearly students reflects to the results during ten following years. Thus, as the number of study places has increased step by step to the state it is in 2021 and the last obtained value from statistics is then maintained throughout the rest of the simulation period, higher initial values since the last statistical year reflects to the results first by more significant increase in the number of graduates. The differences between results of simulations 1a-1c is however purely due the difference in degree completion efficiency. After the year 2034 in simulation results, there is no more effect in outcomes because of the increased number of study places, why the predictions of the simulation 1c (no improvement) is constant till the end of the simulation period.

The difference of results between the extremes of coloured lines (simulation 1a) is around 200 students indicating the variance of the GBM realizations. Followingly, the difference between results of simulation 1b, in which study completion time and the rate of FTE students both are increased, and the simulation 1c (no improvement) is around 900 students at the end of the simulation period. The difference between results of simulation 1a, in which only target time graduation is enhanced, and 1c (no improvement) is around 500 students. The results are numerically presented in the Appendix 8. Overall, the first illustration to the importance of study completion time together with a reduced number of intermediate years during studies in terms of enhancing the transition from higher education to work life or Master's studies can be denoted. In this simulation, the students that enhanced study completion involve about 62 percent of all students, why we could hypothesize the outcome to be more significant, if all age groups will begin completing studies more efficiency.

Next, in the simulation 2 (diverged policy responds) and simulation 3 (diverged policy responds and fixed study place allocation) we assumed, that different universities enhance their performance univariately meaning, that in some universities the share of those completing their studies in a target time increases more significantly among the youngest age group, whereas some universities respond only moderately to the incentive set to enhance the study progress. In Figure 20, averaged results of the number of graduates among the youngest age group are presented under the conditions that yearly study places in universities increase by one to three percent based on the performance, and study places are allocated based on the historical distribution (simulation 2) or with the higher proportion (simulation 3).

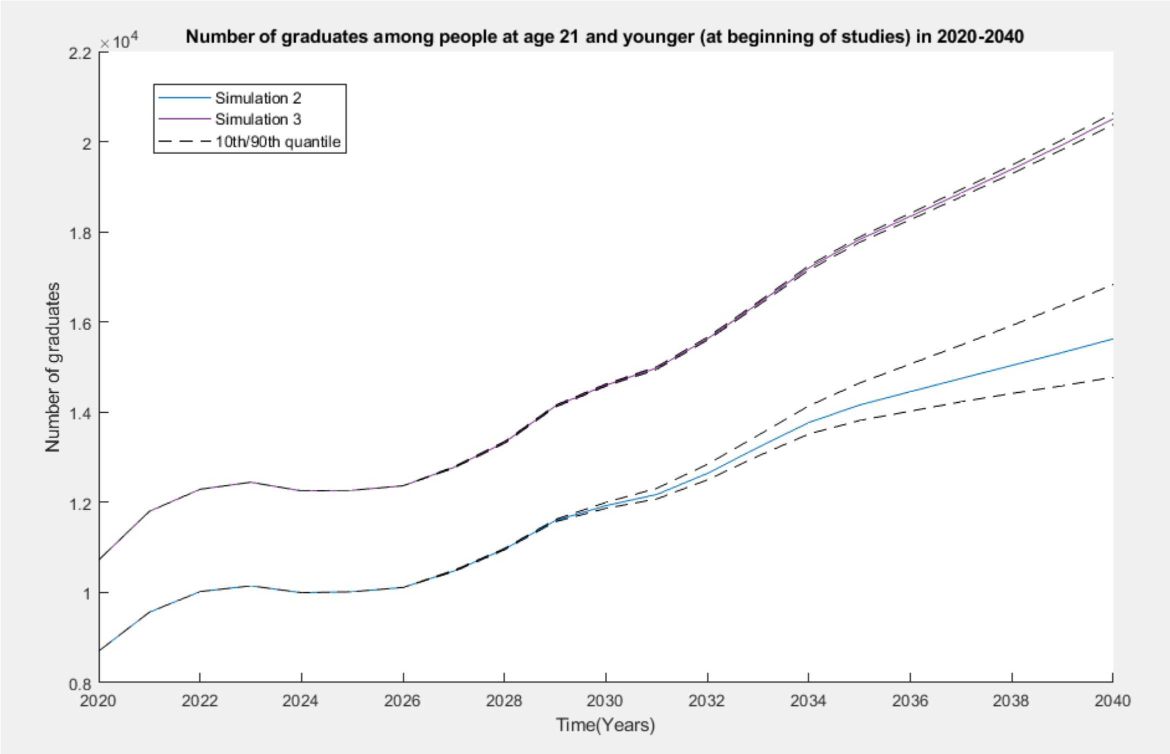


Figure 20. The number of Bachelor level graduates of people at age 21 and under (at beginning of studies) in 2020-2040 based on the simulation 2: diverged policy responds and simulation 3: diverged policy responds and fixed study place allocation. Solid lines represent averaged results and dashed lines correspond to 10^{th} and 90^{th} quantiles

Obviously, the third simulation provides higher number of graduates since 75 percent of study places are allocated to the youngest age group in each university, other conditions being similar than in the second simulation. As seen, the variance in the averaged results of the second simulation is wider. This is, as in the third simulation, the higher proportion of students that enhance the study progress year by year, universities will likely fulfil performance criterion inserted in the model function that regulates increase of new study places, are likely to boost again improved performance. Thus, it seems that in each university, the performance has either fulfilled or not fulfilled the function criteria in each simulation round with respect to the GBM realizations, and results are following similar patterns. Instead, in the second simulation, results spread more variably into different paths, because in some simulation rounds, some universities might variably fulfil or not fulfil the performance criteria, why the number of overall graduates of these also varies more significantly.

Lastly, the plots in the Figure 21 illustrate the averaged results of the second simulation from the university-level perspective, upper plot illustrating the number of young graduates and the plot below the fund allocated to universities. Different trends in the number of graduates are due the initial assumption that institutions response differently to the education policy change and financial incentives, and those capable of enhancing the study processes are likely introducing higher number of study places in upcoming years, which again reflects to the number of graduates.

In terms of core funding, University of Helsinki is losing its competitive advantage over other universities during the simulation period, which is due the condition that some other universities are increasing their yearly number of students and also, obtaining more degree points by enhanced degree completion times (see again, Chapter 5.4). Indeed, the averaged share of core funding allocated to University of Helsinki decreased around 9 percent during the simulation period, which means 7.7 million euros difference between years 2020 and 2040 based on the constant total amount of core funding assumed being allocated in this study based on the Bachelor’s degrees. In some universities, there is only a moderate change in the share of core funding, whereas the University of Lappeenranta-Lahti (LUT) increases its averaged share of funding about 4.5 percent during the simulation period, meaning 2.9 million euros difference between years 2020 and 2040. The averaged results of the simulation 2 are presented in Appendix 9.

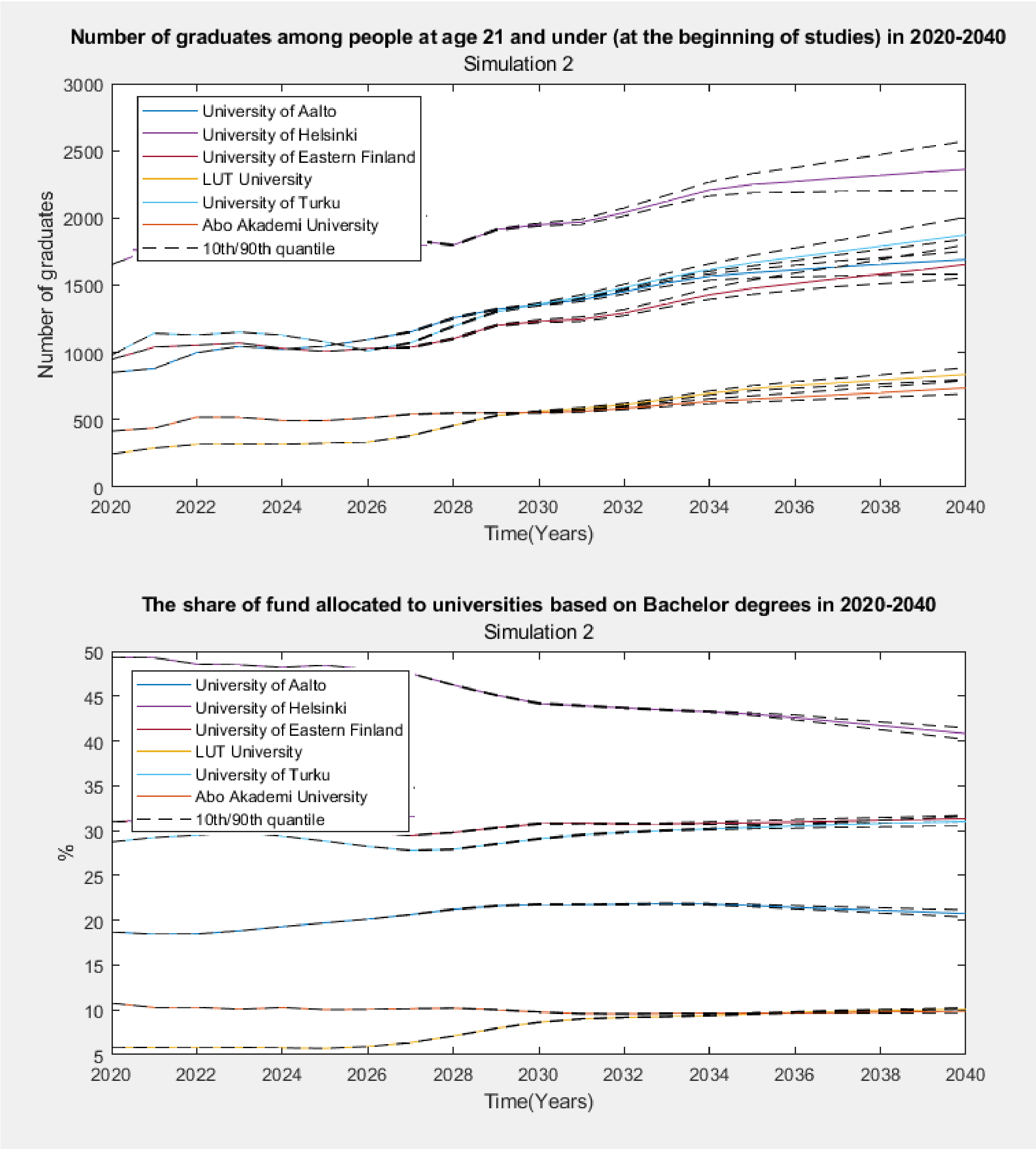


Figure 21. The number of graduates among the youngest age group (21 and under at the beginning of studies) and the share of fund allocate to universities in 2020-2040 based on the simulation 2. Solid lines represent averaged results and dashed lines correspond to 10^{th} and 90^{th} quantiles

The result indicates how the performance-based funding model favours target time graduations meaning, that universities with a higher share of degrees completed within three years receive more degree points per graduate, that provide competitive advantage over those having the smaller proportion of target time graduations. For example, in the case of

University of Helsinki, degree points are accrued because of the university's volume in terms of number of students, although in the degree points calculation, the university achieves smaller results that it could obtain with more efficient study progresses in terms of target time graduates. Undoubtedly, it can be believed that if University of Helsinki enhances its performance in terms of study progresses, it could dominate the fund allocation significantly with both, volume in terms of its size and the degree points achieved with higher coefficients in core funding calculation (see, Table 3 in Chapter 5.2). Accordingly, a smaller university that improves its productivity in terms of increasingly shorter study periods can improve its position in competing for funding.

5.7 Results analysis

It was shown that the simulation model can be used to test different initial conditions regarding the study progress and study place allocations that influence on the university productivity in terms of number of Bachelor's level graduates. As demonstrated in this report with three illustrative analyses, with the model it is possible to test how the number of graduated people at young age and in total will evolve, if study places are allocated more to the first-time university applicants. Also, it is possible to explore the combined effect if intermediate years are reduced and students will complete a degree with a shortened study time. Examination of the results is possible in both, national and university level perspectives. Thus, the model is useful not only at the ministerial level assessments, but also provides possibilities for individual university to monitor its performance, identify its pitfalls and strengths, and later on with further model developments, optimize its internal funding. It is also believed that the simulation model can be modified to describe the degree system in other countries as well.

Although scenarios drawn on the simulation phase were for demonstration purposes, based on the results one can identify in which extend more effective study progress impacts on the yearly number of graduates. The sensitivity of universities to grant extra time for studies is reflected in results as a slow degree completion, and shorter study time alone impacts on the annual number of graduates, even no more study places are allocated to universities. However, by simply increasing the share of people graduating in a target time does not eliminate the issue that students take intermediate years. Also, because of the military service, some proportion of especially male students enrols to the studies after a one-year delay. It should be mentioned that the possible renewal of compulsory military service might lead to increased number of women conducting voluntary military service in future, which in turn might lead to the situation that increased share of women transit to studies after a one-year delay, providing again interesting perspective for further simulations.

The strategy envisioned through the simulation model considers, that only universities that improve their performance will be sensitive to increase the number of new study places, which will be reflected in the university's productivity more significantly forming a reinforcing loop, based on which, the university will likely continue being productive in terms of enhanced study progresses in future.

In university-level evaluation, the effective study progress is important especially in smaller universities from the perspective of core fund allocation, as degree points on which the calculation of core funding is based on are accrued not in terms of student volume but in terms of enhanced performance in these universities. Therefore, a smaller university can improve its competitive advantage alongside larger universities if students complete their studies more in a target time.

Although it was decided to exclude the study program-specific breakdown from the model for data-related reasons, the current model can also be used in such a way that the university entities in turn represent one study program. In this way, instead of university-level behaviour, the performance of students in a particular study program can be modelled in a national level. In addition, the simulation model constructed in the study also involves information about student-person-year ratio, even in this study, we focused on reporting results related to number of graduates only. It has to be also mentioned that, in this study the focus was not on delving into the means how universities enhance their study processes and what are the reasons for slow or fast study processes. However, by widening the model by adding for example variable, that concerns number of students conducting exchange studies will provide more possibilities to model the causalities, as it is known that student exchange has impact on the study completion time.

6. Conclusions and discussion

The purpose of the study was to carry out a system dynamic modeling project in collaboration with the Ministry of Education and Culture of Finland. The motivation of the study was based on the ministry's interest to obtain experience in the use of modern simulation tools with predictive capabilities for the purpose of education policy assessment. The modeling project focused especially to government's goal to improve the efficiency of higher education, which aims at a faster transition of young population to working life with higher education.

From the perspective of methodology, the goal was to contribute to the research of the topic by utilizing systems dynamic simulation modeling and Monte Carlo approach, those together provide a more comprehensive way to explore alternative future scenarios considering stochastic features in the system. The study purpose was to build a simulation model that captures the structure of degree system of Finnish universities and its connection to the national performance-based funding scheme. Followingly, the goal of the developed simulation model was to test alternative scenarios considering the number of admitted students and study progresses dynamically, those combined effect influence on the number of yearly graduates. The aim was to provide to the client insight into the model behaviour and how the model might assist learning about the university productivity.

The research was carried out participatively using principles of action research and group model building. The overall progress of the study was a flexible process in which stakeholders were actively involved in the development of the model. The university system was first described in a qualitative manner using model diagrams. To illustrate the dynamics of the system, several feedback loops were identified as initial assumptions to construct quantitative models. The simulation model was then constructed using Matlab Simulink, and Monte Carlo approach was applied to conduct sensitivity analysis of the simulations. To prepare the simulations, Geometric Brownian motion was utilized as a mathematical uncertainty presentation to draw alternative future paths for proportion of graduation times.

In terms of the overall modeling project, the study highlights the importance to present the simulation model outcomes in a manner that the project stakeholders obtain insight about the usefulness of the method and its capabilities to study the topic under consideration. Thus, the significance of graphical presentations is emphasized as they are useful in describing the model's ability to increase understanding of the research topic. From the modeler perspective, the importance to keep the overall project goal in mind during the study process so that the final results will fill the requirements set to the project is denoted. Additionally, the study stresses the importance of data availability and usability, which might affect significantly on the model initialization phase and later on, to the possibility to obtain reliable simulation results and model validation.

Lastly, although there is a lot of uncertainty in the results of the model as in any forecasts, the system dynamics method with Monte Carlo approach is promising since it is capable to model systems involving causal relationships and nonlinearities, that are due the time delay between the input and its effect. Indeed, in this project it was essential to capture the required number of time delays involved in the study progression to describe the problem of inefficient study progress of Finnish universities in a reliable manner.

To the best of my knowledge, the systems dynamic simulation model together with the Monte Carlo method in the prediction of university performance has not yet been implemented in this extent yet, why it is believed that this contribution provides new perspectives on the study of the topic. As such, models that differentiate the behaviour of age groups and as such, take better account of for example first-time university students have been lacking. Accordingly, the study progress of yearly classes has not been examined on a similar detailed level in the past studies, whereas the model developed in this study considers several time delays existing in the system simultaneously, also adjusting the number of new admitted students in a dynamic manner. It is concluded that study objectives were reached, and the simulation model is capable of capturing the structure of the university degree system and its connection to the performance-based funding model, as it was intended for.

6.1 Answering the research questions

This chapter provides detailed answers to the research questions stated based on the study goal.

RQ1: What possibilities system dynamics modeling provides in monitoring university performance on a national system level based on the existing literature?

The literature review supports the notion of SD modeling as a promising strategic planning and performance evaluation tool for higher education management, since the technique allows a long-term analysis of the system behaviour. Most of the papers contributing to the research topic in past focus mainly on modeling the university level performance and solving institutional level financing, resource, and capacity planning problems. For example, in terms of university demand, it is found that SD modeling with predictive capabilities provides possibilities to measure the number of future student enrolment and required number of study places. Also, from the perspective of human resource planning, the optimal allocation of teaching staff resources between university departments can be solved using a SD model. Although SD modeling with Monte Carlo simulation approach to forecast the number of university graduates was not presented in earlier studies, couple of papers published in past share similar research objectives with a target to examine future enrolments (see, Al Hallak et al. 2019; Frances 1994; Strauss & Borenstein 2014).

RQ2: What kind of System dynamics model describes the Finnish university degree system and what does the model show about future developments of university productivity?

In the SD-model describing the university degree system, relevant time delays in the model structure that mimic the real-world system are one of the most important model components. When predicting the performance of several age groups and universities simultaneously, it is also important to evaluate how these time delays might vary among different parties. The issue is similar if there would be degree program-specific inputs. The key variables important to define the degree systems are the number of new students, the share of FTE-students, and the proportions of different degree completion times. The model should also take account the time gap there might be when students are admitted to university studies and when they are actually starting their studies. In the simulation model, it is reasonable to consider one model time step presenting one academic year. Also, several subsystems are preferred to be constructed to present each university entity so that the inputs are easier to be managed. From the funding perspective, the model should calculate degree points respect to the OKM’s funding scheme, which means that the number of yearly graduates need to be converted into degree points relevantly. Thus, the model needs to calculate degrees that are completed in a target time, one year late and thereafter in each university separately, in order to follow the OKM’s funding model degree point coefficients.

The simulation model developed in the study forecasts the yearly number of graduated Bachelor’s students at Finnish universities and provides information about the study progress in terms of proportion of people graduating in target time and thereafter. The results of the simulation are obtained in three separated age groups to achieve insight especially into the performance of young people who transit into the higher education just after finishing the secondary education. The model also produces an annual estimate of the funding allocated to each university and the student-person-year ratio. In this way, the model can test, how an individual university can improve its competitive advantage in funding alongside another university by enhancing students' graduation time and increasing the number of yearly study places. Indeed, smaller universities are found to have the opportunity to increase their share of core funding through a more efficient degree system, especially if this justifies the allocation of additional study places.

Overall, the simulation model can illustrate the problem of inefficient study progress of Finnish universities and the impact of an enhanced degree system both at the national level and from the perspective of universities when competing for funding. The model can be used for testing the impact of a possible education policy change on university performance when universities have varying sensitivities to respond to incentives. This, however, requires information about the institutions’ possible reactions to the change, discussed further in the context of answering the third research question. The simulation model provides information on both the most optimistic possible scenario, where study time is expected to be significantly more efficient compared to history, and a pessimistic assessment if the degree system cannot be made more efficient. The Monte Carlo simulation allows several simultaneous simulations to be run, providing possibilities to identify the range on which the simulation results might end up, as the pure effect of policy changes is challenging to measure. Also, the model is able to illustrate the results under different alternative scenarios.

For example, a modeler can test the combined effect of increased number of study places and an enhanced degree system on the number of yearly graduates. In addition, the model can be used to test how different strategies for allocating study places to first time students or different age groups affect, for example, to the number of degrees completed by young people.

RQ3: What are the main constraints in modeling the impact of an education policy change on future university performance?

From the technical side, many of the papers examined during the study highlight the challenge to develop an accurate simulation model capable of describing the complex university system and causalities that are underlying in the system. In particular, time delays between the action, such as the policy change and output, the university performance in this case, is acknowledged as one of the main difficulties to be measured. Indeed, several papers (see, Auranen & Nieminen 2010; Buckle & Creedy 2012; Galbraith 2009; Geuna & Martin 2003; Mathies et al. 2019; Seuri & Vartiainen 2018; Sivertsen & Aagaard 2017) highlight the overall challenge to measure the potential effect of a certain indicator of the performance-based funding model to university productivity why also assessing the impact of policy change on performance is similarly problematic. One reason what makes the evaluation difficult is the lack of sufficient data available to assess the pure effect of incentive, since there might be many other external factors that can lead to change. For example, in Finland, changes in study grant requirements took place at the same time as the change in funding models during the past decade (see, Seuri & Vartiainen 2018), which makes it challenging to assess the pure impact of an indicator that rewards faster graduation on university performance. In addition, the effect of incentive on performance might also be temporary, why uncertainties in simulation results increases when predictions are made for a longer time period. Similarly, some considerations are also presented (see, Finnish Union of University Professors 2021) about the importance of weight of a certain indicator in the funding model. Thus, it is difficult to evaluate, whether the higher weight of the indicator in the funding model may have the same incentive effect than the lower weight and probably, if the funding model involves several indicators, the overall impact of a single indicator may be less. These considerations increase the difficulty to evaluate the impact of change in the funding scheme on university performance also when conducting simulations.

6.2 Limitations

As discussed in the previous paragraph, predicting future university performance and testing the impact of education policy change is challenging due the difficulty to measure the pure effect of incentive on university productivity. As such, when modeling the university performance, one should keep in mind the uncertainty of forecasts as in any predictions. For example, student performance, which partially describes the university productivity through study progress is affected by, among other things, differences in student material, the number and quality of student services, the number of teaching personnel and quality of teaching. Many of these are not directly measurable, such as the student's ability to complete studies as it may involve individual-level causes that on the other hand, can be influenced by several other factors in society. Thus, it is challenging to make assumptions about how large, for example, the share of people graduating in a target time can develop, even though it could be possible to assume which universities and degree programs will likely find practices to enhance the study progression. Given the scope of the study, previously mentioned issues were acknowledged when testing the developed model, however, the emphasis was not in analysing the universities responsiveness in a more comprehensive manner. Instead, the primary purpose of the study was to provide a technically viable model that demonstrates the potential of simulation modeling to explore the study topic.

In terms of the study process, at the beginning of any similar modeling project, it is suggested to consider the time required for possible data processing phase which on the other hand, have an important role in model initialization purposes. As noted in this study, even a small extension or additional component build to the model requires more data collection, processing and analyzing, which is the main reason to the model boundaries and delimitations set during this study. Also, although there are extensive educational data available in Vipunen database, there were still some limits in data from past as for example, to validate the model with historical values was challenging, as the model requires statistics from one up to ten years so that the overall results, for example in terms of number of graduates, can be obtained.

6.3 Model validation

With the purpose of constructing a model that describes the real-world Bachelor's level degree system in Finnish universities in its best possible way, the model validation activity started right at the beginning of the modeling phase. Thus, the model structure and its functionality were evaluated at various stages of model development process. In the model, all variables have real life counterparts similarly than initial parameter values, and logical relationships described through model diagrams are, in the light of the best knowledge, compatible with the real system. The OKM experts' knowledge of the connections included in the university system helped to form the connections within the model.

Experiments with real data obtained from Vipunen database were conducted to indicate that the model is sufficient large enough to describe the study progresses of universities and that it can reproduce major behaviour patterns of real-world system. Particular attention was paid to evaluate the number of time delay functions to be involved in the model so that the model could describe the graduation time of Finnish university students realistically. Therefore, the model was extended several times simultaneously during the data analysis phase important for the study, so that the results of the model are in line with the real-world processes. Although some limits in data availability were addressed that affected to the model validation phase discussed also in the Chapter 5.4, it could be concluded that the model is capable of replicating the real number of completed Bachelor's degrees in past.

Overall, the study demonstrated the importance of data analysis during the modeling project especially if the model is developed to describe an existing system that involves several delays between inputs and outputs. Therefore, if too few time delays describing the study period had been used in this study, the model would give unrealistic, too positive picture of the effectiveness of the Finnish universities in terms of study progresses. In addition, to ensure the model robustness, as the model include a function that regulate the number of new study places allocated to universities based on past performance, sensitivity analyses were performed during the function development phase to ensure that the initial algorithm of the function works so that experiments can be conducted, and realistic results obtained.

6.4 Future research

It is believed, that with further development, the model provides even more opportunities to capture the dynamic structures within the university system. First, the model can be continued to involve also the Master's level degree structure. Also, a variable describing, for example, the number of students completing exchange studies and its connection to study progress is additional way to wider the current model by involving other measurable factors that are known to be related to the length of study completion time. Overall, this thesis encourages to continue the study with a more extensive project, as time resources required to the data analysis phase was acknowledged as one of the study limitations in this case.

The study highlights the benefit of applying a system dynamic approach to get insight of the university performance also in the future at both the ministerial and institutional level. It is suggested to continue the research and to take benefit of the capability of predictive simulation model and the Monte Carlo method to capture both, current state of university system and the possible future performance, which might involve stochastic features. There is especially room for a wider study, which focuses in a more comprehensive manner on measuring first the universities' sensitivity to response to education policy change, which then provides starting point to conduct simulations and test further scenarios with the model.

References

Aagaard, K. & Schneider, J. 2017. Some considerations about causes and effects in studies of performance-based research funding systems. Journal of informetrics, Vol.11 (3), pp. 923-926.

Adam, E. 2020. 'Governments base performance-based funding on global rankings indicators': A global trend in higher education finance or a global rankings literature fiction? A comparative analysis of four performance-based funding programs. International Journal of Educational Development. Vol. 76, pp. 102-197.

Al Hallak, L., Ayoubi, A., Moscardini, A. & Loufti, M. 2019. A system dynamic model of student enrolment at the private higher education sector in Syria. Studies in Higher Education. Vol. 44. No. 4, pp. 663-682.

Alaluusua, P. 2020. Rahoitusmalliin kytketyn yliopistokoulutuksen simulointi. Pro gradu. University of Oulu. Available: http://jultika.oulu.fi/files/nbnfioulu-202006182592.pdf

Andersen, D. F., Richardson, E., & Macdonald, R. 2020. System dynamics applications to public policy. System dynamics: Theory and Applications, 253-271.

Andersen, D. F., Richardson, G. P., & Vennix, J. A. 1997. Group model building: adding more science to the craft. System dynamics Review: The Journal of the System dynamics Society. Vol. 13(2), pp. 187-201.

Asl, G. S. P., & Zendeh, A. B. 2014. Strategic plan compilation using System dynamics modeling: case study of a university. Education, Business and Society: Contemporary Middle Eastern Issues.

Aslani, A., Helo, P., & Naaranoja, M. 2014. Role of renewable energy policies in energy dependency in Finland: System dynamics approach. Applied energy. Vol. 113, pp. 758-765.

Auranen, O., & Nieminen, M. 2010. University research funding and publication performance—An international comparison. Research policy. Vol. 39(6), pp. 822-834.

Barber, P., & López-Valcárcel, B. G. 2010. Forecasting the need for medical specialists in Spain: application of a System dynamics model. Human resources for health. Vol. 8(1), pp. 1-9.

Barlas, Y., & Diker, V. G. 2000. A dynamic simulation game (UNIGAME) for strategic university management. Simulation & Gaming. Vol. 31(3), pp. 331-358.

Birta, L. G., & Arbez, G. 2013. Modelling and simulation. London: Springer.

Borshchev, A., & Filippov, A. 2004. From System dynamics and discrete event to practical agent based modeling: reasons, techniques, tools. In Proceedings of the 22nd international conference of the System dynamics society. Vol. 22, pp. 25-29.

Brandimarte, P. 2014. Handbook in Monte Carlo simulation: applications in financial engineering, risk management, and economics. John Wiley & Sons.

Buckle, R. A., & Creedy, J. 2018. The impact on research quality of performance-based funding: the case of New Zealand’s PBRF scheme. Agenda: A Journal of Policy Analysis and Reform. Vol. 25(1), pp. 25-48.

Casper, C. A., & Henry, M. S. 2001. Developing performance-oriented models for university resource allocation. Research in Higher Education. Vol. 42(3), pp. 353-376.

Checchi, D., Malgarini, M., & Sarlo, S. 2019. Do performance-based research funding systems affect research production and impact? Higher Education Quarterly. Vol. 73(1), pp. 45-69.

Cho, W. K. T., & Liu, Y. Y. 2018. Sampling from complicated and unknown distributions: Monte Carlo and Markov Chain Monte Carlo methods for redistricting. Physica A: Statistical Mechanics and its Applications. Vol. 506, pp. 170-178.

Clark, J. S., Porath, S., Thiele, J., & Jobe, M. 2020. Action research. New Prairie Press.

Cosenz, F., & Bianchi, C. 2013. Designing performance management systems in academic institutions: A dynamic performance management view. In ASPA conference 2013.

Dahlan, S. M., & Yahaya, N. A. 2010. A System dynamics model for determining educational capacity of higher education institutions. In: Second International Conference on Computational Intelligence, Modelling and Simulation, pp. 285-290.

Dandagi, S., Bhushi, U., Bagodi, V., & Sinha, D. 2016. Strategic management of technical university: structural equation modelling approach. Journal of Modelling in Management. Vol. 11 No. 1, pp. 75-90.

De Boer, H., Jongbloed, B., Benneworth, P., Cremonini, L., Kolster, R., Kottmann, A., & Vossensteyn, H. 2015. Performance-based funding and performance agreements in fourteen higher education systems. Center for Higher Education Policy Studies.

Dooley, K. 2002. Simulation research methods. Companion to organizations, pp. 829-848.

Finnish Innovation Fund Sitra 2020. Väestöselvitys 2040. Ikäryhmäkohtaiset ja alueelliset väestöennusteet sekä uusien opiskelijoiden määrien ennuste kaikilla koulutusasteilla Suomessa 2018–2040. ISBN 978-952-347-170-2.

Frances, C., Alstyne, M. V., Ashton, A., & Hochstettler, T. 1994. Using System dynamics technology to improve planning and budgeting for higher education: Results in Arizona and Houston, Texas. In 1994 International System dynamics Conference.

Galbraith, P. L. 1998. System dynamics and university management. System dynamics Review: The Journal of the System dynamics Society. Vol. 14(1), pp. 69-84.

Galbraith, P. 2010. System dynamics: A lens and scalpel for organisational decision making. OR insight. Vol. 23(2), pp. 96-123.

Geuna, A., & Martin, B. R. 2003. University research evaluation and funding: An international comparison. Minerva. Vol. 41(4), pp. 277-304.

Gomez Diaz, M, 2012. Unintended Effects of Changes in NIH Appropriations: Challenges for Biomedical Research Workforce Development. Massachusetts Institute of Technology.

Gunawan, R., Cao, Y., Petzold, L., & Doyle III, F. J. 2005. Sensitivity analysis of discrete stochastic systems. Biophysical journal. Vol. 88(4), pp. 2530-2540.

Hovmand, P. S., Andersen, D. F., Rouwette, E., Richardson, G. P., Rux, K., & Calhoun, A. 2012. Group model-building ‘scripts’ as a collaborative planning tool. Systems Research and Behavioral Science. Vol. 29(2), pp. 179-193.

Ishikawa, T., Ohba, H., Yokooka, Y., Nakamura, K., & Ogasawara, K. 2013. Forecasting the absolute and relative shortage of physicians in Japan using a System dynamics model approach. Human resources for health. Vol. 11(1), pp. 1-10.

Jonkers, K., & Zacharewicz, T. 2016. Research performance-based funding systems: A comparative assessment. Publications Office of the European Union, Luxembourg.

Kauffman, D. L. 1980. Systems one: An introduction to systems thinking. Future Systems, Incorporated.

Karhunen, H., Pekkarinen, T., Suhonen, T., & Virkola, T. 2021. Opiskelijavalintauudistuksen seurantatutkimuksen väliraportti. VATT Institute for Economic Research. Helsinki 2021.

Kennedy, M. 1998. A pilot System dynamics model to capture and monitor quality issues in higher education institutions experiences gained. In Proceedings of the 16th System dynamics conference, Canada.

Kennedy M. & Clare C. 1998. Some Issues in System dynamics Model Building to Support Quality Monitoring in Higher Education. Information Management and Modelling Group. Proceedings of the 17th International Conference.

van Kersbergen, R. J., van Daalen, C. E., Meza, C. C., & Horlings, E 2015. The Impact of Career and Funding Policies on the Academic Workforce in The Netherlands. Delft University of Technology. Proceedings of the 34th International Conference of the System dynamics Society.

Kivistö, J., Pekkola, E. & Kujala, E. 2021. Selvitys yliopistojen sisäisistä rahoitusmalleista. Osa 1: Yliopistojen sisäiset rahoitusmallit. Professoriliitto.

Mathies, C., Kivistö, J., & Birnbaum, M. 2020. Following the money? Performance-based funding and the changing publication patterns of Finnish academics. Higher Education. Vol. 79(1), pp. 21-37.

McCardle-Keurentjes, M. H., Rouwette, E. A., Vennix, J. A., & Jacobs, E. 2018. Potential benefits of model use in group model building: insights from an experimental investigation. System dynamics Review. Vol. 34(1-2), pp. 354-384.

Mella, P. 2012. Systems thinking: intelligence in action. Vol. 2. Springer Science & Business Media.

Ministry of Education and Culture 2019. Education and Learning, Knowledge, Science and Technology for the Benefit of People and Society. Available: https://okm.fi/documents/1410845/4177242/Proposal+for+Finland.pdf/08a7cc61-3e66-4c60-af75-d44d1877787d/Proposal+for+Finland.pdf?t=1532701164000

Ministry of Education and Culture 2021. Higher education and degrees. Available: https://okm.fi/en/higher-education-and-degrees

Ministry of Education and Culture 2021. Higher education institutions, science agencies, research institutes and other public research organisations. Available: https://okm.fi/en/heis-and-science-agencies

Ministry of Education and Culture 2021. Policy and development in higher education and science. Available: https://okm.fi/en/policy-and-development-in-higher-education-and-science

Ministry of Education and Culture 2021. Steering, financing and agreements of higher education institutions, science agencies and research institutes. Available: https://okm.fi/en/steering-financing-and-agreements

Ministry of Education and Culture 2021. The Finnish education system. Available: https://okm.fi/en/education-system

Mitleton-Kelly, E. 2003. Complex systems and evolutionary perspectives on organisations: the application of complexity theory to organisations. Elsevier Science Ltd.

Morecroft, J. D. 2015. Strategic modelling and business dynamics: A feedback systems approach. John Wiley & Sons.

OECD 2020. Education at a Glance 2020: OECD Indicators. OECD Publishing, Paris. Available: https://doi.org/10.1787/69096873-en.

Oyo, B., Williams, D., & Barendsen, E. 2008. A System dynamics Tool for Higher Education Funding and Quality Policy Analysis. In Proceedings of the 24th International Conference of the System dynamics Society.

Pölönen, J., Pylvänäinen, E., Aspara, J., Puuska, H. M., & Rinne, R. 2021. Publication Forum 2010–2020: Self-evaluation report of the Finnish quality classification system of peer-reviewed publication channels.

Richardson, G. P. 2020. Core of System dynamics. System dynamics: Theory and Applications.

Robledo, L. F., Sepulveda, J., & Archer, S. 2013. Hybrid simulation decision support system for university management. In: Winter Simulations Conference (WSC), pp. 2066-2075.

Rouwette, E. A., Vennix, J. A., & Felling, A. J. 2009. On evaluating the performance of problem structuring methods: An attempt at formulating a conceptual model. Group Decision and Negotiation. Vol. 18(6), pp. 567-587.

Rouwette, E. A., Vennix, J. A., & Mullekom, T. V. 2002. Group model building effectiveness: a review of assessment studies. System dynamics Review: The Journal of the System dynamics Society. Vol. 18(1), pp. 5-45.

Schwaninger, M. 2020. System dynamics in the evolution of the systems approach. System dynamics: Theory and Applications, pp. 21-39.

Scott, R. 2018. Group model building: Using systems dynamics to achieve enduring agreement. Springer.

Scott, R. 2019. Explaining how group model building supports enduring agreement. Journal of Management & Organization Vol. 25(6), pp. 783-806.

Seuri, A. & Vartiainen, H. 2018. Yliopistojen rahoitus, kannustimet ja rakennekehitys. Kansantaloudellinen aikakauskirja. Vol. 114.

Sivertsen, G., & Aagaard, K. 2017. The effects of performance-based research funding systems. In R-QUEST policy brief. Vol. 2, pp. 1-4.

Sterman, J. D. 2001. System dynamics modeling: tools for learning in a complex world. California management review. Vol. 43(4), pp. 8-25.

Sterman, J. 2002. System dynamics: systems thinking and modeling for a complex world.

Sterman, J. D. 2006. Learning from evidence in a complex world. American journal of public health. Vol. 96(3), pp. 505-514.

Somekh, B. 2005. Action research. McGraw-Hill Education (UK).

Strauss, L. M., & Borenstein, D. 2015. A System dynamics model for long-term planning of the undergraduate education in Brazil. Higher Education. Vol. 69(3), pp. 375-397.

Székely Jr, T., & Burrage, K. 2014. Stochastic simulation in systems biology. Computational and structural biotechnology journal. Vol. 12(20-21), pp. 14-25.

The Official Statistics of Finland 2019. Population projection. The decline in the birth rate is reflected in the population development of areas. Available: https://www.stat.fi/til/vaenn/2019/vaenn_2019_2019-09-30_tie_001_fi.html

Vanderby, S. A., Carter, M. W., Latham, T., & Feindel, C. 2014. Modelling the future of the Canadian cardiac surgery workforce using System dynamics. Journal of the Operational Research Society. Vol. 65(9), pp. 1325-1335.

Vennix, J. A. 1999. Group model-building: tackling messy problems. System dynamics Review: The Journal of the System dynamics Society, Vol. 15(4), pp. 379-401.

Vennix, J. A., Akkermans, H. A., & Rouwette, E. A. 1996. Group model-building to facilitate organizational change: an exploratory study. System dynamics Review: The Journal of the System dynamics Society. Vol. 12(1), pp. 39-58.

Vipunen - Education Statistics Finland 2021. All levels and sectors. Available: https://vipunen.fi/en-gb/all-levels-and-sectors

Vipunen - Education Statistics Finland 2021. Higher education and r&d activity. Available: https://vipunen.fi/en-gb/higher-education-and-r-d-activity

Vipunen - Education Statistics Finland 2021. University Education. Available: https://vipunen.fi/en-gb/university-education

Vokueva, O. 2017. Model-based university management: System dynamics approach. Master’s Thesis. Lappeenranta University of Technology. School of Business and Management. Available: http://urn.fi/URN:NBN:fi-fe2017121155595

Zacharewicz, T., Lepori, B., Reale, E., & Jonkers, K. 2019. Performance-based research funding in EU Member States—a comparative assessment. Science and Public Policy. Vol. 46(1), pp. 105-115.

Zaini, R. M., Pavlov, O. V., Saeed, K., Radzicki, M. J., Hoffman, A. H., & Tichenor, K. R. 2017. Let's talk change in a university: A simple model for addressing a complex agenda. Systems Research and Behavioral Science. Vol. 34(3), pp. 250-266.

Zio, E. 2013. The Monte Carlo Simulation Method for System Reliability and Risk Analysis. Springer.

Önsel, N., & Barlas, Y. 2011. Modeling the dynamics of academic publications and citations. Doctoral dissertation, MS Thesis, Bogazici University

Appendices

Appendix 1. Project timeline and meetings with the project team

During the modeling project, the planning of the work was carried out and the progress was monitored mainly through meetings held remotely.

Date	**Purpose**
15.4.2021	The project kick-off
7.5.2021	Topic identification
28.5.2021	Topic clarifications, data related practices
14.6.2021	Monitoring the progress of the project
22.6.2021	Monitoring the progress of the project
1.7.2021	Data related practices
18.8.2021	Introduction of the model draft. Model variables and model boundaries are clarified.
6.9.2021	Monitoring the progress of the project
12.10.2021	The second model version and development ideas
22.11.2021	Introduction of the final model
13.12.2021	Project summary

Appendix 2. Simulation model inputs

Appendix 2.1. The number of study places. The number of study places has increased during 2010-2021 which obsiously affects to the number of completed degrees increasingly as well.

Vuosi	Aalto University	University of Helsinki	University of Eastern Finland	University of Jyväskylä	University of Lapland	University of LUT	University of Oulu	Hanken School of Economics	University of Arts	University of Tampere	University of Turku	University of Vaasa	Åbo Akademi University
2010	1491	3506	2137	1595	550	499	1733	293	174	2183	2058	569	784
2011	1522	3578	2180	1627	562	509	1768	299	177	2228	2100	581	800
2012	1553	3651	2225	1660	573	520	1804	305	181	2273	2143	593	816
2013	1585	3725	2270	1694	585	530	1841	311	184	2319	2187	605	833
2014	1617	3801	2317	1729	597	541	1879	318	188	2367	2231	617	850
2015	1647	3870	2364	1764	612	552	1917	324	192	2415	2274	633	867
2016	1698	3801	2166	1773	594	531	1809	309	219	2349	2172	588	717
2017	1740	3654	2082	1689	558	531	1770	311	183	2442	2184	531	726
2018	1827	3747	2070	2016	573	534	1902	345	195	2475	2244	624	795
2019	2022	3831	2139	1905	588	645	1878	354	186	2610	2298	690	834
2020	2469	4512	2553	2049	705	849	2178	423	183	2940	2724	849	966
2021*	2502	4509	2937	2250	771	1089	2403	348	204	3153	3045	798	975

*in Simulation 1 the value of year 2021 remains constant till the end of the simulation period. In simulations 2 and 3 the number of study places are managed by the model component. Optionally the modeller can fix the number of study places through the Excel user interface.

Appendix 2.2. Study places allocated to age groups. There are differences in universities how study places have been allocated to age groups. It can be seen that in LUT university around 82 percent of study places were distributed to the youngest age group in 2021, whereas for example in the University of Arts the share was only around 37 percent.

People at age 21 and under at the beginning of studies													
Year	**Aalto University**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**University of Arts**	**University of Tampere**	**University of Turku**	**University of Vaasa**	**Åbo Akademi University**
2010	75 %	51 %	55 %	64 %	47 %	84 %	61 %	77 %	55 %	64 %	62 %	65 %	73 %
2011	75 %	51 %	55 %	64 %	47 %	84 %	61 %	77 %	55 %	64 %	62 %	65 %	73 %
2012	75 %	51 %	55 %	64 %	47 %	84 %	61 %	77 %	55 %	64 %	62 %	65 %	73 %
2013	75 %	51 %	55 %	64 %	47 %	84 %	61 %	77 %	55 %	64 %	62 %	65 %	73 %
2014	75 %	51 %	55 %	64 %	47 %	84 %	61 %	77 %	55 %	64 %	62 %	65 %	73 %
2015	75 %	51 %	55 %	64 %	47 %	84 %	61 %	77 %	55 %	64 %	62 %	65 %	73 %
2016	75 %	52 %	54 %	61 %	43 %	85 %	63 %	81 %	47 %	66 %	61 %	63 %	71 %
2017	78 %	54 %	53 %	57 %	49 %	88 %	64 %	83 %	44 %	67 %	62 %	63 %	74 %
2018	80 %	51 %	52 %	59 %	46 %	88 %	64 %	86 %	49 %	67 %	60 %	71 %	69 %
2019	80 %	49 %	50 %	59 %	48 %	80 %	68 %	81 %	46 %	64 %	60 %	70 %	71 %
2020	76 %	55 %	54 %	56 %	52 %	81 %	66 %	77 %	50 %	66 %	62 %	69 %	74 %
2021 onwards*	78 %	52 %	50 %	56 %	47 %	82 %	63 %	77 %	37 %	65 %	58 %	69 %	67 %

*fixed to 75 % in the simulation 3

Appendix 2.3. The share of new students starting their studies at the same year being admitted. Based on the statistics it seems that the youngest age group has the highest share of people not attending the studies the same year being admitted. One reason for this is the military service.

People at age 21 and under at the beginning of studies													
Year	**University of Aalto**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**University of Arts**	**University of Tampere**	**University of Turku**	**University of Vaasa**	**Åbo Akademi University**
2010	68 %	84 %	81 %	79 %	88 %	60 %	74 %	78 %	94 %	72 %	84 %	79 %	72 %
2011	68 %	84 %	81 %	79 %	88 %	60 %	74 %	78 %	94 %	72 %	84 %	79 %	72 %
2012	68 %	84 %	81 %	79 %	88 %	60 %	74 %	78 %	94 %	72 %	84 %	79 %	72 %
2013	68 %	84 %	81 %	79 %	88 %	60 %	74 %	78 %	94 %	72 %	84 %	79 %	72 %
2014	68 %	84 %	81 %	79 %	88 %	60 %	74 %	78 %	94 %	72 %	84 %	79 %	72 %
2015	68 %	84 %	81 %	79 %	88 %	60 %	74 %	78 %	94 %	72 %	84 %	79 %	72 %
2016	67 %	81 %	81 %	79 %	83 %	53 %	72 %	75 %	94 %	71 %	84 %	77 %	77 %
2017	61 %	83 %	81 %	80 %	92 %	55 %	74 %	76 %	89 %	72 %	86 %	78 %	74 %
2018	63 %	81 %	82 %	79 %	92 %	55 %	72 %	69 %	88 %	72 %	81 %	70 %	76 %
2019	60 %	83 %	83 %	81 %	87 %	54 %	74 %	61 %	93 %	72 %	79 %	67 %	74 %
2020	58 %	73 %	75 %	78 %	79 %	54 %	68 %	65 %	87 %	69 %	73 %	66 %	72 %
2021 onwards	57 %	73 %	73 %	73 %	79 %	53 %	64 %	71 %	96 %	64 %	69 %	66 %	68 %

22-24 years and younger at the beginning of studies													
Year	**University of Aalto**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**University of Arts**	**University of Tampere**	**University of Turku**	**University of Vaasa**	**Åbo Akademi University**
2010	93 %	93 %	89 %	89 %	91 %	91 %	92 %	100 %	100 %	93 %	93 %	100 %	88 %
2011	93 %	93 %	89 %	89 %	91 %	91 %	92 %	100 %	100 %	93 %	93 %	100 %	88 %
2012	93 %	93 %	89 %	89 %	91 %	91 %	92 %	100 %	100 %	93 %	93 %	100 %	88 %
2013	93 %	93 %	89 %	89 %	91 %	91 %	92 %	100 %	100 %	93 %	93 %	100 %	88 %
2014	93 %	93 %	89 %	89 %	91 %	91 %	92 %	100 %	100 %	93 %	93 %	100 %	88 %
2015	93 %	93 %	89 %	89 %	91 %	91 %	92 %	100 %	100 %	93 %	93 %	100 %	88 %
2016	93 %	94 %	92 %	90 %	85 %	89 %	92 %	93 %	96 %	94 %	94 %	95 %	88 %
2017	92 %	94 %	93 %	95 %	95 %	88 %	90 %	93 %	100 %	94 %	94 %	94 %	90 %
2018	94 %	95 %	95 %	92 %	98 %	87 %	92 %	91 %	100 %	92 %	96 %	89 %	86 %
2019	89 %	94 %	95 %	93 %	98 %	96 %	94 %	93 %	100 %	93 %	96 %	91 %	85 %
2020	84 %	86 %	89 %	88 %	91 %	94 %	88 %	95 %	93 %	89 %	89 %	85 %	81 %
2021 onwards	87 %	86 %	92 %	92 %	91 %	89 %	89 %	95 %	95 %	89 %	88 %	89 %	81 %

25 years and older at the beginning of studies													
Year	**University of Aalto**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**University of Arts**	**University of Tampere**	**University of Turku**	**University of Vaasa**	**Åbo Akademi University**
2010	88 %	92 %	87 %	84 %	89 %	100 %	88 %	100 %	93 %	90 %	90 %	91 %	84 %
2011	88 %	92 %	87 %	84 %	89 %	100 %	88 %	100 %	93 %	90 %	90 %	91 %	84 %
2012	88 %	92 %	87 %	84 %	89 %	100 %	88 %	100 %	93 %	90 %	90 %	91 %	84 %
2013	88 %	92 %	87 %	84 %	89 %	100 %	88 %	100 %	93 %	90 %	90 %	91 %	84 %
2014	88 %	92 %	87 %	84 %	89 %	100 %	88 %	100 %	93 %	90 %	90 %	91 %	84 %
2015	88 %	92 %	87 %	84 %	89 %	100 %	88 %	100 %	93 %	90 %	90 %	91 %	84 %
2016	87 %	93 %	91 %	85 %	88 %	67 %	90 %	100 %	94 %	95 %	92 %	93 %	84 %
2017	93 %	92 %	93 %	89 %	91 %	83 %	93 %	100 %	100 %	92 %	91 %	100 %	91 %
2018	92 %	93 %	93 %	91 %	95 %	71 %	90 %	60 %	100 %	92 %	91 %	90 %	83 %
2019	85 %	93 %	91 %	91 %	94 %	87 %	90 %	88 %	100 %	92 %	94 %	89 %	80 %
2020	86 %	90 %	89 %	90 %	93 %	84 %	87 %	82 %	100 %	88 %	90 %	89 %	79 %
2021 onwards	89 %	90 %	89 %	89 %	92 %	82 %	86 %	100 %	92 %	89 %	85 %	92 %	83 %

Appendix 2.4. The proportion of FTE-students. The proportion of FTE-students means those students that participate to studies during the academic year.

People at age 21 years and under at the beginning of studies													
Year	**Aalto University**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**University of Arts**	**University of Tampere**	**University of Turku**	**University of Vaasa**	**A Ur**
2010	69 %	86 %	81 %	81 %	87 %	62 %	74 %	76 %	84 %	73 %	83 %	77 %	
2011	70 %	85 %	80 %	80 %	87 %	64 %	74 %	78 %	84 %	73 %	82 %	80 %	
2012	71 %	86 %	81 %	81 %	85 %	64 %	74 %	73 %	87 %	73 %	83 %	79 %	
2013	71 %	85 %	82 %	82 %	85 %	70 %	75 %	77 %	89 %	75 %	84 %	79 %	
2014	72 %	84 %	84 %	82 %	88 %	65 %	76 %	76 %	94 %	76 %	84 %	78 %	
2015	74 %	86 %	87 %	85 %	90 %	67 %	80 %	82 %	91 %	78 %	87 %	83 %	
2016	74 %	87 %	88 %	86 %	92 %	66 %	80 %	82 %	90 %	78 %	88 %	84 %	
2017	69 %	88 %	89 %	86 %	93 %	66 %	81 %	80 %	91 %	79 %	89 %	85 %	
2018	72 %	88 %	89 %	86 %	95 %	67 %	80 %	78 %	89 %	79 %	88 %	81 %	
2019	75 %	89 %	90 %	87 %	93 %	69 %	79 %	74 %	92 %	80 %	86 %	80 %	
2020	76 %	89 %	88 %	86 %	92 %	70 %	78 %	76 %	92 %	79 %	85 %	81 %	
2021 onwards*	76 %	89 %	88 %	86 %	93 %	72 %	78 %	77 %	92 %	79 %	85 %	82 %	

*fixed up to 90 % in the simulation 2 and simulation 3 from 2021 onwards in some universities

22-24 years at the beginning of studies													
Year	**Aalto University**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**University of Arts**	**University of Tampere**	**University of Turku**	**University of Vaasa**	**Åbo Akademi University**
2010	83 %	85 %	85 %	86 %	86 %	83 %	86 %	85 %	79 %	83 %	85 %	87 %	83 %
2011	84 %	85 %	85 %	89 %	86 %	85 %	86 %	85 %	84 %	83 %	87 %	87 %	83 %
2012	86 %	85 %	85 %	89 %	86 %	85 %	86 %	85 %	84 %	83 %	87 %	87 %	83 %
2013	88 %	86 %	85 %	89 %	87 %	85 %	86 %	87 %	88 %	83 %	88 %	87 %	83 %
2014	88 %	87 %	86 %	89 %	89 %	88 %	88 %	87 %	88 %	86 %	89 %	87 %	83 %
2015	87 %	88 %	87 %	90 %	89 %	89 %	89 %	89 %	88 %	87 %	90 %	89 %	85 %
2016	88 %	88 %	89 %	90 %	92 %	88 %	89 %	89 %	88 %	88 %	90 %	90 %	85 %
2017	87 %	90 %	90 %	90 %	93 %	91 %	89 %	90 %	88 %	88 %	91 %	92 %	86 %
2018	87 %	90 %	91 %	90 %	93 %	91 %	90 %	90 %	88 %	89 %	91 %	92 %	89 %
2019	88 %	90 %	91 %	90 %	93 %	91 %	90 %	90 %	90 %	90 %	91 %	92 %	90 %
2020	91 %	90 %	91 %	90 %	93 %	91 %	90 %	92 %	90 %	90 %	91 %	92 %	90 %
2021 onwards	91 %	90 %	92 %	90 %	93 %	91 %	90 %	92 %	95 %	90 %	91 %	92 %	89 %

25 years and older at the beginning of studies													
Year	**Aalto University**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**University of Arts**	**University of Tampere**	**University of Turku**	**University of Vaasa**	**Åbo Akademi University**
2010	59 %	60 %	65 %	68 %	68 %	58 %	60 %	60 %	73 %	58 %	63 %	58 %	55 %
2011	58 %	60 %	64 %	69 %	66 %	56 %	60 %	63 %	73 %	57 %	67 %	57 %	55 %
2012	58 %	61 %	64 %	69 %	66 %	56 %	60 %	63 %	77 %	57 %	67 %	57 %	55 %
2013	58 %	62 %	64 %	70 %	66 %	56 %	60 %	63 %	81 %	57 %	69 %	60 %	57 %
2014	58 %	63 %	64 %	70 %	68 %	56 %	61 %	63 %	82 %	59 %	71 %	60 %	58 %
2015	58 %	64 %	64 %	71 %	69 %	56 %	61 %	63 %	82 %	60 %	72 %	60 %	60 %
2016	58 %	65 %	64 %	69 %	70 %	56 %	69 %	63 %	82 %	60 %	73 %	60 %	60 %
2017	58 %	65 %	65 %	71 %	71 %	56 %	69 %	63 %	82 %	61 %	73 %	60 %	60 %
2018	58 %	66 %	67 %	71 %	71 %	56 %	69 %	63 %	85 %	64 %	73 %	60 %	60 %
2019	58 %	67 %	66 %	71 %	71 %	59 %	69 %	63 %	88 %	65 %	74 %	60 %	64 %
2020	59 %	69 %	68 %	71 %	71 %	61 %	70 %	65 %	86 %	70 %	75 %	60 %	65 %
2021 onwards	62 %	71 %	71 %	71 %	73 %	67 %	74 %	66 %	86 %	70 %	77 %	60 %	67 %

22-24 years at the beginning of studies													
Year	**Aalto University**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**University of Arts**	**University of Tampere**	**University of Turku**	**University of Vaasa**	**Åbo Akademi University**
2010	13 %	20 %	19 %	18 %	22 %	12 %	18 %	17 %	22 %	15 %	19 %	19 %	15 %
2011	13 %	20 %	19 %	18 %	22 %	12 %	18 %	17 %	22 %	15 %	19 %	19 %	15 %
2012	13 %	20 %	19 %	18 %	22 %	12 %	18 %	17 %	22 %	15 %	19 %	19 %	15 %
2013	13 %	20 %	19 %	18 %	22 %	12 %	18 %	17 %	22 %	15 %	19 %	19 %	15 %
2014	13 %	20 %	19 %	18 %	22 %	12 %	18 %	17 %	22 %	15 %	19 %	19 %	15 %
2015	13 %	20 %	19 %	18 %	22 %	12 %	18 %	17 %	22 %	15 %	19 %	19 %	15 %
2016	13 %	20 %	19 %	19 %	28 %	10 %	19 %	14 %	31 %	16 %	19 %	22 %	13 %
2017	12 %	19 %	21 %	21 %	22 %	9 %	18 %	14 %	25 %	15 %	19 %	19 %	12 %
2018	10 %	19 %	20 %	18 %	22 %	8 %	17 %	10 %	25 %	14 %	21 %	18 %	13 %
2019	10 %	19 %	21 %	19 %	20 %	13 %	17 %	13 %	21 %	16 %	19 %	19 %	15 %
2020	13 %	17 %	18 %	20 %	19 %	12 %	17 %	15 %	23 %	15 %	17 %	18 %	10 %
2021 onwards*	11 %	18 %	19 %	19 %	22 %	10 %	17 %	15 %	28 %	16 %	18 %	18 %	11 %

*fixed to 12.5 % in the simulation 3

25 years and older at the beginning of studies													
Year	**Aalto University**	**University of Helsinki**	**University of Eastern Finland**	**University of Jyväskylä**	**University of Lapland**	**University of LUT**	**University of Oulu**	**Hanken School of Economics**	**Universit y of Arts**	**University of Tampere**	**University of Turku**	**Univers ity of Vaasa**	**Åbo Akademi University**
2010	12 %	29 %	26 %	18 %	32 %	4 %	21 %	6 %	23 %	21 %	19 %	17 %	13 %
2011	12 %	29 %	26 %	18 %	32 %	4 %	21 %	6 %	23 %	21 %	19 %	17 %	13 %
2012	12 %	29 %	26 %	18 %	32 %	4 %	21 %	6 %	23 %	21 %	19 %	17 %	13 %
2013	12 %	29 %	26 %	18 %	32 %	4 %	21 %	6 %	23 %	21 %	19 %	17 %	13 %
2014	12 %	29 %	26 %	18 %	32 %	4 %	21 %	6 %	23 %	21 %	19 %	17 %	13 %
2015	12 %	29 %	26 %	18 %	32 %	4 %	21 %	6 %	23 %	21 %	19 %	17 %	13 %
2016	12 %	28 %	27 %	20 %	29 %	5 %	19 %	6 %	22 %	18 %	20 %	15 %	16 %
2017	10 %	27 %	26 %	22 %	29 %	3 %	17 %	3 %	31 %	18 %	19 %	18 %	14 %
2018	10 %	30 %	28 %	23 %	32 %	4 %	18 %	4 %	26 %	19 %	18 %	10 %	18 %
2019	10 %	31 %	28 %	22 %	32 %	7 %	16 %	7 %	33 %	19 %	21 %	12 %	15 %
2020	11 %	28 %	27 %	24 %	29 %	7 %	17 %	8 %	27 %	19 %	21 %	12 %	16 %
2021 onwards*	11 %	30 %	32 %	25 %	31 %	8 %	20 %	9 %	35 %	19 %	24 %	14 %	22 %

*fixed to 12.5 % in the simulation 3

Appendix 3. Excel user-interface

There are several sheets involving tables for inputs, which user can then manage. Inputs are connected to Matlab.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P

Taulukon ohjeet:

Välilehdet toimivat syötteenä Matlabiin.

Malli 1 tarkastelee alemman korkeakoulututkintojen määrää ikäluokittain ja suoritusajoittain:

- 18-21 vuotiaat
- 21-24 vuotiaat
- 25 ja yli vuotiaat

Malli ei erottele yliopistoja. Mallilla voidaan seurata suoritettujen tutkintojen suhdetta väestöennusteen mukaiseen ikäluokkien määrään sekä tutkintopisteiden muodostumista tutkinnoista eri suoritusnopeuksin.

INPUT - välilehdellä (malli 1) voit muuttaa arvoja FTE- opiskelijoiden osuuteen, sekä testata rahoitusmallin mukaisen tutkintopistekertoimen muutoksen vaikutusta tuloksiin. Lisäksi voit testata eri tutkinnon suoritusaikojen vaikutusta eri ikäluokkien suoriutumiseen rahoitusmallin jaotelman mukaisesti:

- tavoiteajassa valmistuneiden osuus
- max 12 kk tavoiteajassa valmistuneiden osuus
- yli 12 kk tavoiteajassa valmistuneiden osuus

Taulukon valmiit toiminnallisuudet:

- **Reset** palauttaa taulukon arvot vastaamaan viimeisintä tilastoi
- **Keskiarvo** on 2015-2020 vuosien keskiarvo
- **Määritelty** käyttää aputaulukkoon syötettyjä arvoja

Valittujen opiskelijoiden taulukolla voit testata valittujen opiske opiskelijoiden kokonaismääriin, jotka sallivat myös eri testien aj

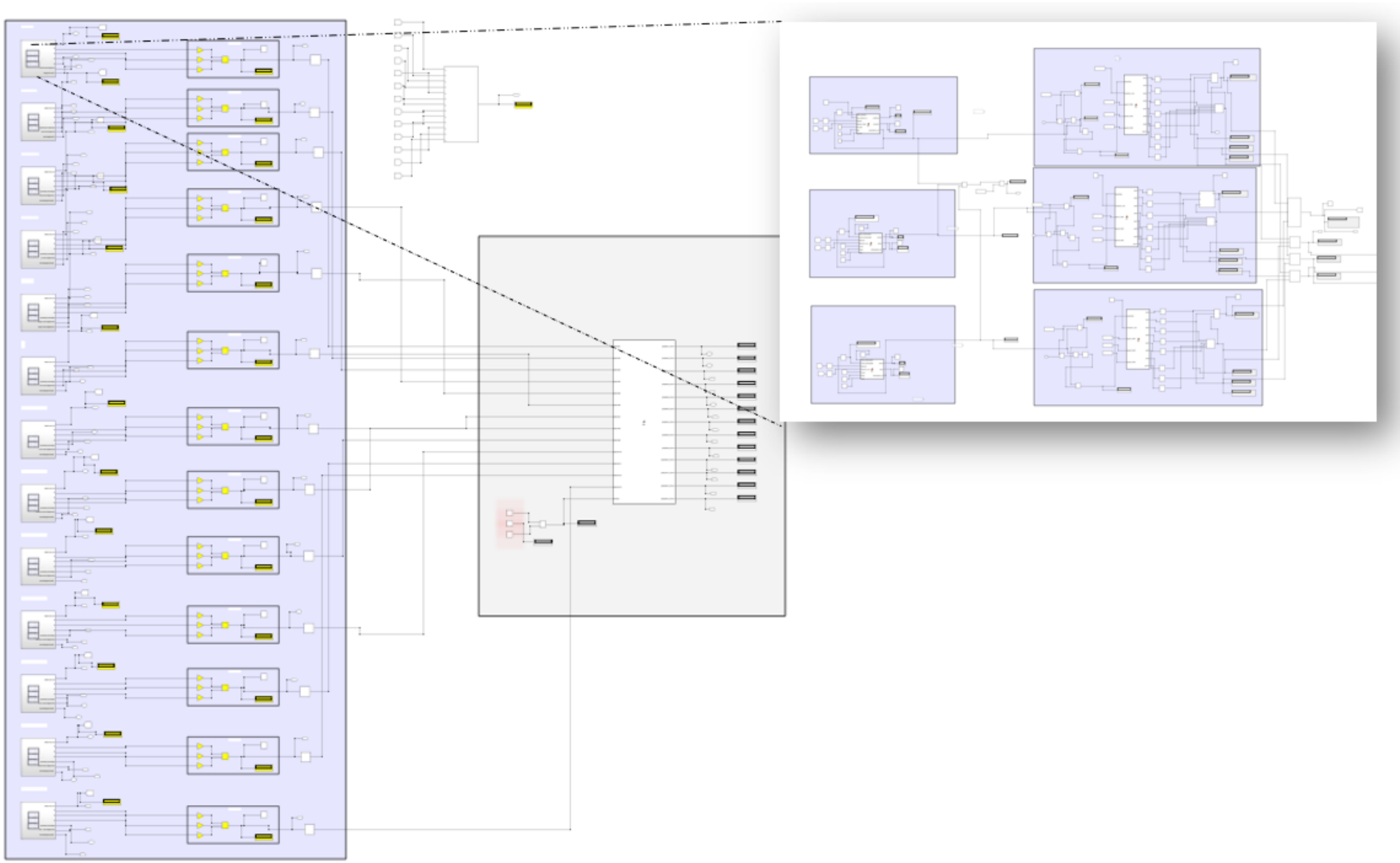
INSTRUCTIONS | INPUT (malli 1) | INPUT (malli 2) | suoritusajat 18-24 (malli 2)

INPUTS	Aalto-yliopisto	Helsingin yliopisto	Itä-Suomen yliopisto	Jyväskylän yliopisto	Lapin yliopisto	Lap
Students starting studies same year being admitted						
<=21v	80,4 %	86,9 %	92,5 %	95,5 %	76,3 %	
22-24v	80,4 %	86,9 %	92,5 %	95,5 %	76,3 %	
>=25v	80,4 %	86,9 %	92,5 %	95,5 %	76,3 %	
Coefficients inputs for fund calculation						
Target time	1,5					
Max 12 months from a target time	1,3					
More than 12 months from a target time	1					
Core funding						
Total amount of core funding	1713823000					
Share of core funding for education	41 %					
Share of funding allocated based on Bachelor's degrees	11 %					

Averaged values of three past years

Appendix 4. The structure of the simulation model in Matlab Simulink

There are 13 separate entities (left side in the figure) that represent each Finnish university as a subsystem. The right-side screenshot in the figure is a high-level illustration of one sub-system, which then involves three separate parts for age groups. The middle grey area is function for core funding calculations, in which number of yearly degrees and obtained degree points of universities are added up, and the amount of core funding is then allocated to universities as “zero-sum game”. This means, that the university with the highest number of degree points achieves the highest share of core funding etc.



Appendix 5. Simulation 1: The GBM realizations for the proportion of the youngest age group graduating in a target time in 2020-2040

Year	University of Aalto	University of Helsinki	University of Eastern Finland	University of Jyväskylä	University of Lapland	University of LUT	University of Oulu	Hanken School of Economics	University of Arts	University of Tampere	University of Turku	University of Vaasa	Åbo Akademi University
2020	45,00 %	25,00 %	44,00 %	45,00 %	45,00 %	42,00 %	48,00 %	22,00 %	47,00 %	39,00 %	36,00 %	32,00 %	45,00 %
2021	46,36 %	25,78 %	45,35 %	46,39 %	46,35 %	43,27 %	49,43 %	22,66 %	48,47 %	40,19 %	37,10 %	32,95 %	46,41 %
2022	47,77 %	26,56 %	46,72 %	47,77 %	47,77 %	44,56 %	50,94 %	23,34 %	49,97 %	41,42 %	38,21 %	33,94 %	47,84 %
2023	49,16 %	27,36 %	48,15 %	49,22 %	49,22 %	45,99 %	52,50 %	24,02 %	51,45 %	42,71 %	39,43 %	34,99 %	49,27 %
2024	50,70 %	28,23 %	49,61 %	50,70 %	50,70 %	47,41 %	54,10 %	24,76 %	53,01 %	44,00 %	40,65 %	36,04 %	50,78 %
2025	52,28 %	29,07 %	51,07 %	52,31 %	52,21 %	48,85 %	55,76 %	25,50 %	54,63 %	45,36 %	41,91 %	37,15 %	52,39 %
2026	53,87 %	29,95 %	52,61 %	53,95 %	53,76 %	50,28 %	57,49 %	26,31 %	56,27 %	46,72 %	43,19 %	38,30 %	53,95 %
2027	55,56 %	30,88 %	54,25 %	55,60 %	55,39 %	51,75 %	59,23 %	27,13 %	58,04 %	48,10 %	44,48 %	39,51 %	55,58 %
2028	57,24 %	31,78 %	55,91 %	57,32 %	57,09 %	53,32 %	61,00 %	27,94 %	59,79 %	49,56 %	45,83 %	40,74 %	57,26 %
2029	59,01 %	32,74 %	57,66 %	59,06 %	58,81 %	54,91 %	62,76 %	28,79 %	61,61 %	51,13 %	47,22 %	42,03 %	59,04 %
2030	60,83 %	33,73 %	59,40 %	60,87 %	60,56 %	56,57 %	64,66 %	29,67 %	63,47 %	52,70 %	48,63 %	43,30 %	60,88 %
2031	62,71 %	34,77 %	61,23 %	62,76 %	62,40 %	58,32 %	66,66 %	30,59 %	65,42 %	54,28 %	50,12 %	44,62 %	62,65 %
2032	64,64 %	35,81 %	63,11 %	64,65 %	64,27 %	60,06 %	68,71 %	31,50 %	67,39 %	55,96 %	51,66 %	46,00 %	64,51 %
2033	66,62 %	36,90 %	64,97 %	66,61 %	66,23 %	61,84 %	70,85 %	32,46 %	69,48 %	57,68 %	53,28 %	47,44 %	66,39 %
2034	68,67 %	38,03 %	66,89 %	68,72 %	68,23 %	63,77 %	72,97 %	33,45 %	71,59 %	59,40 %	54,91 %	48,89 %	68,40 %
2035	70,76 %	39,17 %	68,96 %	70,73 %	70,31 %	65,71 %	75,17 %	34,49 %	73,77 %	61,25 %	56,59 %	50,39 %	70,51 %
2036	72,95 %	40,36 %	71,00 %	72,95 %	72,52 %	67,73 %	77,44 %	35,56 %	75,97 %	63,09 %	58,39 %	51,94 %	72,75 %
2037	75,21 %	41,57 %	73,15 %	75,17 %	74,71 %	69,80 %	79,82 %	36,60 %	78,21 %	65,01 %	60,19 %	53,59 %	74,95 %
2038	77,43 %	42,84 %	75,40 %	77,41 %	77,02 %	71,88 %	82,25 %	37,71 %	80,66 %	67,05 %	62,02 %	55,20 %	77,30 %
2039	79,77 %	44,18 %	77,65 %	79,82 %	79,34 %	74,04 %	84,74 %	38,85 %	83,15 %	69,14 %	63,96 %	56,91 %	79,57 %
2040	82,10 %	45,54 %	79,94 %	82,29 %	81,73 %	76,32 %	87,36 %	40,06 %	85,67 %	71,21 %	66,00 %	58,56 %	82,01 %

Appendix 6. Internal funding models of Finnish universities (Finnish Union of University Professors 2021 / Professoriliitto 2021)

	Tulosrahoituksen osuus sis. mallissa %	Koulutuksen osuus (100%)	Tutkimuksen osuus (100 %)	Indikaattorien lkm.	OKM-indikaattoreita	Akateemisten tulosyksiköiden määrä	Akat. tulosyksiköillä tulosperusteinen alamalli	Akat. tulosyksikkö pitää mahdollisen ylijäämän	Tulosbonukset palkassa
Aalto-yo	32 % *	30 %	70 %	9	6	6	Linjassa yliopiston mallin kanssa, mutta huomioivat erityispiireet	Kyllä	Ei
Helsingin yo	10 %	25 % (+ vaihtuva ind.)	25 % (+ vaihtuva ind.)	4	0,5	12	Yksikön päätettävissä	Kyllä	Ei
Itä-Suomen yo	71 % **	55 %	45 %	16	11	4	Yksikön päätettävissä	Ei	Ei
Jyväskylän yo	40 % ***	55 %	45 %	11 + 4	11	6	Yksikön päätettävissä	Ei	Ei
Lapin yliopisto	76 %	55 %	45 %	11	10	7	Ei	Ei	Ei
LUT-yliopisto	90 %	61 %	49 %	11	11	3	Yksikön päätettävissä	Harkinnanvarainen mahdollisuus (50 %)	Kyllä
Oulun yliopisto	70 %	53 %	47 %	17	11	8	Yksikön päätettävissä	Päätetään TTS-neuvotteluissa	Ei henkiöstölle, kyllä johdolle
Tampereen yo	20 %	48 %	48 %	7	8	7	Ei	Ei	Ei
Turun yo	20 %	54 %	46 %	10	9	8	Yksikön päätettävissä	Osittain, 3 vuoden keskiarvon mukaan	Ei
Svenska handelshögskolan	8 %	47 %	53 %	7	3	4	Ei	Osittain, 1/3 ylijäämästä	Ei
Vaasan yo	Ei tulosperusteista mallia							Kyllä, tietyin edellytyksin	
Åbo Akademi	85 %	55 %	45 %	10	9	4	Ei	Harkinnanvarainen mahdollisuus (40 %)	Ei

* vuosi 2021 (tavoite 30 %); ** tdk keskiarvo, vaihtelee tiedekunnittain; *** tdk keskiarvo, vaihtelua tiedekunnittain, lisäksi vaikuttaa perusosan laskentaperiaatten kautta

Appendix 7. Simulation 2 and 3: The GBM realizations for the proportion of the youngest age group graduating in a target time in 2020-2040

Year	University of Aalto	University of Helsinki	University of Eastern Finland	University of Jyväskylä	University of Lapland	University of LUT	University of Oulu	Hanken School of Economics	University of Arts	University of Tampere	University of Turku	University of Vaasa	Åbo Akademi University
2020	45,00 %	25,00 %	44,00 %	45,00 %	45,00 %	42,00 %	48,00 %	22,00 %	47,00 %	39,00 %	36,00 %	32,00 %	45,00 %
2021	45,13 %	25,08 %	45,34 %	46,35 %	46,38 %	43,27 %	49,45 %	22,56 %	48,21 %	39,78 %	36,75 %	32,33 %	46,36 %
2022	45,24 %	25,15 %	46,74 %	47,82 %	47,78 %	44,60 %	51,01 %	23,14 %	49,43 %	40,57 %	37,48 %	32,65 %	47,77 %
2023	45,41 %	25,23 %	48,16 %	49,27 %	49,21 %	45,95 %	52,59 %	23,73 %	50,69 %	41,39 %	38,25 %	32,98 %	49,27 %
2024	45,55 %	25,33 %	49,64 %	50,71 %	50,73 %	47,31 %	54,17 %	24,31 %	51,97 %	42,24 %	39,02 %	33,31 %	50,81 %
2025	45,70 %	25,40 %	51,14 %	52,24 %	52,27 %	48,80 %	55,83 %	24,93 %	53,26 %	43,08 %	39,81 %	33,65 %	52,34 %
2026	45,86 %	25,48 %	52,71 %	53,81 %	53,86 %	50,28 %	57,49 %	25,56 %	54,64 %	43,93 %	40,63 %	33,94 %	53,94 %
2027	46,02 %	25,55 %	54,30 %	55,45 %	55,47 %	51,79 %	59,24 %	26,22 %	56,05 %	44,80 %	41,49 %	34,25 %	55,61 %
2028	46,16 %	25,62 %	55,92 %	57,11 %	57,11 %	53,36 %	61,09 %	26,88 %	57,47 %	45,69 %	42,33 %	34,61 %	57,31 %
2029	46,30 %	25,69 %	57,66 %	58,87 %	58,86 %	54,95 %	62,97 %	27,58 %	58,95 %	46,62 %	43,19 %	34,97 %	59,04 %
2030	46,46 %	25,76 %	59,41 %	60,67 %	60,69 %	56,64 %	64,94 %	28,26 %	60,41 %	47,55 %	44,04 %	35,33 %	60,78 %
2031	46,59 %	25,85 %	61,29 %	62,48 %	62,53 %	58,38 %	66,92 %	28,98 %	61,90 %	48,50 %	44,88 %	35,68 %	62,62 %
2032	46,68 %	25,94 %	63,17 %	64,40 %	64,44 %	60,13 %	69,05 %	29,74 %	63,44 %	49,45 %	45,74 %	36,03 %	64,53 %
2033	46,83 %	26,01 %	65,03 %	66,35 %	66,42 %	61,95 %	71,14 %	30,45 %	65,00 %	50,48 %	46,66 %	36,42 %	66,45 %
2034	46,97 %	26,08 %	67,01 %	68,38 %	68,42 %	63,86 %	73,29 %	31,19 %	66,69 %	51,50 %	47,62 %	36,79 %	68,47 %
2035	47,10 %	26,15 %	69,02 %	70,47 %	70,51 %	65,79 %	75,50 %	31,98 %	68,34 %	52,52 %	48,57 %	37,16 %	70,56 %
2036	47,25 %	26,22 %	71,08 %	72,64 %	72,68 %	67,81 %	77,75 %	32,83 %	70,08 %	53,62 %	49,57 %	37,54 %	72,73 %
2037	47,35 %	26,30 %	73,25 %	74,89 %	74,86 %	69,84 %	80,18 %	33,67 %	71,86 %	54,67 %	50,64 %	37,93 %	74,90 %
2038	47,47 %	26,36 %	75,46 %	77,10 %	77,16 %	72,00 %	82,60 %	34,50 %	73,70 %	55,81 %	51,66 %	38,31 %	77,23 %
2039	47,65 %	26,44 %	77,74 %	79,39 %	79,51 %	74,19 %	85,09 %	35,38 %	75,57 %	56,95 %	52,67 %	38,69 %	79,60 %
2040	47,79 %	26,53 %	80,08 %	81,81 %	81,96 %	76,49 %	87,64 %	36,26 %	77,52 %	58,11 %	53,72 %	39,05 %	81,95 %

Appendix 8. Simulation 1: Results

Different results of simulations 1a-1c is because of the changes in study processes. The simulation 1b (equal policy responds and fixed FTE-rate) leads to the highest number of degrees at the end of the simulation period and can those be seen as the most optimistic scenario.

1a: equal policy respond			1b: equal policy responds and fixed FTE-rate			1c: no improvement		
Total number of degrees			Total number of degrees			Total number of degrees		
Year	**All**	**The youngest age group**	**Year**	**All**	**The youngest age group**	**Year**	**All**	**The youngest age group**
2020	15573	9506	2020	15573	9763	2020	15573	9763
2021	16666	10356	2021	16666	10356	2021	16666	10356
2022	17310	10726	2022	17310	10726	2022	17310	10726
2023	17067	10677	2023	17074	10677	2023	17000	10609
2024	17130	10732	2024	17145	10732	2024	16992	10593
2025	17502	10978	2025	17517	10978	2025	17358	10834
2026	18587	11663	2026	18611	11663	2026	18304	11358
2027	20217	12622	2027	20246	12622	2027	19864	12236
2028	21386	13455	2028	21984	14016	2028	20952	12982
2029	21784	13756	2029	22386	14322	2029	21372	13307
2030	21909	13852	2030	22510	14418	2030	21513	13417
2031	22071	13974	2031	22637	14496	2031	21677	13534
2032	22255	14114	2032	22770	14579	2032	21851	13661
2033	22452	14265	2033	22899	14655	2033	22037	13797
2034	22573	14363	2034	22979	14713	2034	22144	13879
2035	22611	14404	2035	23010	14741	2035	22170	13904
2036	22626	14424	2036	23031	14763	2036	22170	13904
2037	22639	14440	2037	23050	14781	2037	22170	13904
2038	22652	14459	2038	23070	14802	2038	22170	13904
2039	22666	14478	2039	23091	14823	2039	22170	13904
2040	22681	14497	2040	23112	14844	2040	22170	13904

Appendix 9. Simulation 2: Results

Appendix 9.1. The number of graduates among people at age 21 years and younger (at beginning of studies) in Finnish universities in 2020-2040.

The number of graduates increases most in the universities considered most sensitive to respond to the policy change, as they improve their efficiency, which again leads to the higher number of study places and again to the higher number of yearly degrees. The increased number of yearly graduates is thus as a combined effect of increased number of study places and more efficient study processes, as more students complete their degrees in a target time.

Year	University of Aalto	University of Helsinki	University of Eastern Finland	University of Jyväskylä	University of Lapland	University of LUT	University of Oulu	Hanken School of Economics	University of Arts	University of Tampere	University of Turku	University of Vaasa	Åbo Akademi University
2020	851	1654	949	822	193	245	943	171	68	1084	981	323	416
2021	881	1772	1039	950	240	290	1023	174	63	1206	1143	344	439
2022	999	1755	1054	926	254	317	1114	203	73	1311	1129	367	519
2023	1046	1830	1071	916	238	319	1089	199	73	1330	1152	367	518
2024	1025	1787	1030	918	245	318	1090	190	68	1355	1129	347	494
2025	1047	1803	1008	953	256	326	1088	191	62	1385	1078	326	493
2026	1097	1801	1029	1005	241	335	1106	179	66	1407	1013	320	513
2027	1153	1836	1037	1019	238	381	1133	184	63	1463	1072	358	541
2028	1256	1798	1102	1017	264	458	1151	217	70	1486	1195	396	550
2029	1322	1912	1201	1055	283	530	1210	221	77	1526	1301	406	551
2030	1356	1949	1231	1089	285	564	1254	212	78	1585	1359	410	554
2031	1392	1969	1247	1096	287	584	1274	220	78	1623	1413	427	564
2032	1452	2040	1293	1121	304	611	1311	232	80	1679	1483	453	585
2033	1516	2125	1362	1162	323	652	1369	238	79	1753	1555	474	611
2034	1566	2208	1430	1209	338	696	1439	239	79	1831	1617	486	635
2035	1593	2249	1477	1243	347	732	1494	238	78	1896	1668	493	653
2036	1613	2270	1513	1268	355	756	1534	241	80	1947	1708	501	668
2037	1637	2296	1549	1295	363	775	1569	246	81	1993	1749	510	685
2038	1657	2317	1583	1323	371	795	1608	251	82	2041	1790	517	702
2039	1674	2340	1617	1348	379	815	1647	257	83	2089	1832	525	719
2040	1691	2360	1656	1377	388	836	1688	263	85	2138	1875	533	737

Appendix 9.2. The share of core funding based on the Bachelor's degree graduates in Finnish universities in 2020-2040

Year	University of Aalto	University of Helsinki	University of Eastern Finland	University of Jyväskylä	University of Lapland	University of LUT	University of Oulu	Hanken School of Economics	University of Arts	University of Tampere	University of Turku	University of Vaasa	Åbo Akademi University
2020	18,83 %	48,48 %	31,05 %	23,59 %	8,08 %	5,85 %	24,25 %	3,81 %	2,63 %	29,38 %	29,85 %	8,00 %	10,08 %
2021	19,30 %	48,21 %	30,84 %	23,47 %	7,99 %	5,78 %	24,46 %	3,65 %	2,67 %	29,99 %	29,41 %	7,85 %	10,28 %
2022	19,72 %	48,45 %	30,43 %	24,08 %	8,03 %	5,74 %	24,25 %	3,52 %	2,79 %	30,60 %	28,84 %	7,41 %	10,03 %
2023	20,12 %	47,99 %	29,85 %	24,83 %	8,10 %	5,94 %	24,33 %	3,49 %	2,75 %	31,07 %	28,23 %	7,14 %	10,06 %
2024	20,65 %	47,54 %	29,48 %	25,14 %	8,04 %	6,36 %	24,21 %	3,44 %	2,61 %	31,27 %	27,79 %	7,22 %	10,15 %
2025	21,23 %	46,24 %	29,79 %	24,75 %	8,01 %	7,11 %	24,00 %	3,56 %	2,51 %	31,03 %	27,92 %	7,55 %	10,20 %
2026	21,61 %	45,11 %	30,32 %	24,15 %	8,12 %	7,96 %	23,77 %	3,61 %	2,42 %	30,54 %	28,51 %	7,76 %	10,03 %
2027	21,78 %	44,19 %	30,78 %	23,78 %	8,19 %	8,63 %	23,74 %	3,60 %	2,39 %	30,22 %	29,10 %	7,74 %	9,77 %
2028	21,76 %	43,94 %	30,84 %	23,52 %	8,13 %	9,02 %	23,79 %	3,49 %	2,36 %	30,24 %	29,53 %	7,68 %	9,59 %
2029	21,79 %	43,69 %	30,76 %	23,28 %	8,07 %	9,18 %	23,79 %	3,45 %	2,33 %	30,44 %	29,81 %	7,74 %	9,58 %
2030	21,84 %	43,45 %	30,78 %	23,04 %	8,07 %	9,28 %	23,73 %	3,45 %	2,29 %	30,53 %	30,03 %	7,81 %	9,61 %
2031	21,80 %	43,25 %	30,82 %	22,90 %	8,09 %	9,40 %	23,78 %	3,40 %	2,25 %	30,59 %	30,19 %	7,80 %	9,63 %
2032	21,65 %	42,96 %	30,88 %	22,81 %	8,10 %	9,58 %	23,93 %	3,32 %	2,22 %	30,71 %	30,37 %	7,72 %	9,65 %
2033	21,45 %	42,60 %	30,95 %	22,77 %	8,10 %	9,74 %	24,11 %	3,27 %	2,19 %	30,87 %	30,54 %	7,66 %	9,67 %
2034	21,27 %	42,16 %	31,05 %	22,76 %	8,12 %	9,85 %	24,25 %	3,24 %	2,18 %	31,02 %	30,68 %	7,62 %	9,70 %
2035	21,11 %	41,71 %	31,14 %	22,80 %	8,13 %	9,93 %	24,38 %	3,25 %	2,17 %	31,15 %	30,79 %	7,58 %	9,75 %
2036	20,94 %	41,27 %	31,23 %	22,84 %	8,15 %	10,00 %	24,52 %	3,25 %	2,16 %	31,28 %	30,90 %	7,55 %	9,81 %
2037	20,75 %	40,83 %	31,32 %	22,88 %	8,17 %	10,07 %	24,67 %	3,26 %	2,15 %	31,41 %	31,01 %	7,51 %	9,87 %
2038	20,55 %	40,36 %	31,45 %	22,93 %	8,20 %	10,14 %	24,81 %	3,27 %	2,14 %	31,52 %	31,12 %	7,48 %	9,94 %
2039	20,36 %	39,89 %	31,56 %	23,02 %	8,22 %	10,21 %	24,96 %	3,29 %	2,14 %	31,62 %	31,21 %	7,44 %	10,00 %
2040	20,16 %	39,42 %	31,67 %	23,10 %	8,24 %	10,28 %	25,12 %	3,30 %	2,13 %	31,72 %	31,29 %	7,39 %	10,07 %

Appendix 9.3. The amount of core funding based on the Bachelor's degree graduates in Finnish universities in 2020-2040. The amount of core funding is fixed to constant (1713823000 €) to the whole simulation period. The last row in the table presents the difference in the amount of core funding in 2020 and 2040.

Year	University of Aalto	University of Helsinki	University of Eastern Finland	University of Jyväskylä	University of Lapland	University of LUT	University of Oulu	Hanken School of Economics	University of Arts	University of Tampere	University of Turku	University of Vaasa	Åbo Akademi University
2020	15 726 494 €	35 924 492 €	20 521 314 €	20 277 233 €	6 501 162 €	5 808 267 €	17 852 313 €	3 331 459 €	2 388 347 €	22 440 485 €	22 082 924 €	7 323 458 €	8 342 583 €
2021	16 354 362 €	35 444 354 €	20 191 752 €	20 060 146 €	6 755 254 €	6 040 835 €	17 488 947 €	3 301 598 €	2 412 429 €	23 303 821 €	21 996 112 €	7 062 110 €	8 108 810 €
2022	16 995 182 €	35 376 230 €	19 923 162 €	20 113 051 €	6 787 262 €	6 050 899 €	17 337 938 €	3 246 031 €	2 511 970 €	23 949 405 €	21 952 677 €	6 579 867 €	7 696 856 €
2023	17 551 119 €	34 906 814 €	19 538 753 €	20 236 237 €	6 700 493 €	6 116 405 €	17 498 874 €	3 272 734 €	2 470 055 €	24 307 078 €	21 873 963 €	6 376 723 €	7 671 283 €
2024	17 996 753 €	34 368 233 €	19 399 334 €	20 029 218 €	6 578 921 €	6 450 559 €	17 671 591 €	3 318 713 €	2 353 985 €	24 223 082 €	21 771 346 €	6 547 529 €	7 811 265 €
2025	18 357 299 €	33 629 843 €	19 489 253 €	19 461 366 €	6 539 961 €	7 039 285 €	17 806 423 €	3 498 710 €	2 254 124 €	23 786 873 €	21 736 348 €	6 941 526 €	7 979 520 €
2026	18 567 403 €	33 128 354 €	19 572 160 €	18 914 714 €	6 614 419 €	7 587 798 €	18 037 331 €	3 686 313 €	2 142 333 €	23 252 621 €	21 735 198 €	7 232 946 €	8 048 941 €
2027	18 723 841 €	32 815 925 €	19 592 692 €	18 631 538 €	6 656 222 €	7 871 544 €	18 293 239 €	3 802 821 €	2 095 411 €	22 974 551 €	21 687 927 €	7 304 309 €	8 070 509 €
2028	18 713 459 €	32 752 529 €	19 566 062 €	18 551 600 €	6 632 234 €	7 961 058 €	18 547 287 €	3 790 996 €	2 058 346 €	22 922 065 €	21 654 900 €	7 264 079 €	8 105 915 €
2029	18 719 938 €	32 542 185 €	19 605 527 €	18 466 093 €	6 608 588 €	8 010 884 €	18 734 034 €	3 763 378 €	2 037 464 €	22 939 892 €	21 670 330 €	7 246 760 €	8 175 456 €
2030	18 733 990 €	32 312 323 €	19 668 312 €	18 368 814 €	6 605 114 €	8 076 157 €	18 857 634 €	3 773 049 €	2 012 216 €	22 884 718 €	21 734 531 €	7 258 801 €	8 234 870 €
2031	18 732 231 €	32 028 140 €	19 740 606 €	18 339 753 €	6 600 540 €	8 141 026 €	18 971 757 €	3 773 685 €	1 988 527 €	22 860 456 €	21 801 044 €	7 250 645 €	8 292 119 €
2032	18 646 743 €	31 708 746 €	19 823 983 €	18 350 408 €	6 595 797 €	8 208 283 €	19 104 722 €	3 770 951 €	1 963 265 €	22 888 707 €	21 885 342 €	7 223 028 €	8 350 554 €
2033	18 504 524 €	31 340 556 €	19 931 239 €	18 379 873 €	6 600 522 €	8 274 370 €	19 255 797 €	3 767 613 €	1 941 971 €	22 940 452 €	21 978 895 €	7 194 271 €	8 410 447 €
2034	18 334 504 €	30 950 783 €	20 045 131 €	18 426 882 €	6 618 526 €	8 337 296 €	19 402 677 €	3 772 712 €	1 926 746 €	22 993 964 €	22 073 848 €	7 166 793 €	8 470 669 €
2035	18 158 960 €	30 531 811 €	20 157 023 €	18 506 492 €	6 639 073 €	8 399 798 €	19 551 537 €	3 779 394 €	1 912 893 €	23 058 054 €	22 166 474 €	7 126 163 €	8 532 859 €
2036	17 964 844 €	30 097 956 €	20 272 177 €	18 604 313 €	6 660 062 €	8 463 870 €	19 697 204 €	3 787 177 €	1 895 847 €	23 140 714 €	22 265 932 €	7 073 094 €	8 597 340 €
2037	17 742 263 €	29 643 314 €	20 394 737 €	18 712 216 €	6 684 573 €	8 531 270 €	19 848 358 €	3 796 679 €	1 879 806 €	23 230 349 €	22 371 156 €	7 021 466 €	8 664 344 €
2038	17 507 511 €	29 181 560 €	20 520 047 €	18 824 635 €	6 715 795 €	8 599 353 €	19 996 544 €	3 808 619 €	1 867 631 €	23 317 779 €	22 474 555 €	6 975 025 €	8 731 477 €
2039	17 269 698 €	28 713 009 €	20 647 852 €	18 944 718 €	6 749 176 €	8 668 124 €	20 146 066 €	3 822 304 €	1 856 705 €	23 408 401 €	22 573 946 €	6 920 260 €	8 800 271 €
2040	17 025 632 €	28 243 836 €	20 777 279 €	19 071 394 €	6 782 911 €	8 736 217 €	20 304 714 €	3 835 889 €	1 842 765 €	23 502 959 €	22 674 554 €	6 854 173 €	8 868 205 €
Diff.	**1 299 138 €**	**-7 680 656 €**	**255 965 €**	**-1 205 838 €**	**281 749 €**	**2 927 950 €**	**2 452 401 €**	**504 430 €**	**-545 581 €**	**1 062 474 €**	**591 630 €**	**-469 285 €**	**525 623 €**

Appendix 9.4. Number of study places in Finnish universities in 2020-2040. The number of study places is controlled by the model function. If the number of target time graduates has increased satisfying the given function rule, the number of study places increases by 3 percent. If the rule is not satisfied, the number of study places increases by 1 percent. The increase in the study places takes place in every second year.

Year	University of Aalto	University of Helsinki	University of Eastern Finland	University of Jyväskylä	University of Lapland	University of LUT	University of Oulu	Hanken School of Economics	University of Arts	University of Tampere	University of Turku	University of Vaasa	Åbo Akademi University	Total
2020	2469	4518	2556	2052	708	857	2178	426	188	2969	2724	849	969	**23464**
2021	2502	4509	2937	2250	771	1100	2403	348	206	3185	3045	798	975	**25028**
2022	2512	4527	2949	2259	774	1104	2413	349	207	3197	3057	801	979	**25129**
2023	2522	4636	2961	2268	777	1131	2471	358	208	3274	3131	820	983	**25539**
2024	2583	4655	3032	2277	796	1158	2481	366	209	3353	3206	840	1006	**25961**
2025	2645	4767	3105	2332	815	1186	2540	375	214	3434	3283	860	1031	**26586**
2026	2658	4786	3180	2388	833	1214	2602	377	214	3516	3362	864	1055	**27050**
2027	2672	4857	3209	2415	841	1243	2663	386	216	3590	3431	879	1073	**27474**
2028	2707	4878	3285	2442	861	1273	2713	395	218	3675	3513	897	1098	**27955**
2029	2758	4948	3364	2501	881	1304	2777	404	224	3761	3595	916	1125	**28558**
2030	2783	4972	3445	2561	901	1335	2845	411	226	3850	3681	922	1152	**29084**
2031	2800	5033	3494	2606	913	1367	2913	421	229	3932	3756	935	1177	**29578**
2032	2829	5058	3576	2646	935	1401	2978	431	232	4021	3842	952	1205	**30103**
2033	2869	5122	3663	2710	957	1434	3049	441	237	4112	3929	969	1234	**30728**
2034	2900	5149	3752	2776	979	1469	3123	450	240	4207	4021	979	1264	**31310**
2035	2923	5212	3816	2834	995	1505	3198	461	244	4298	4102	992	1295	**31875**
2036	2952	5241	3905	2886	1019	1541	3274	472	248	4393	4192	1008	1326	**32457**
2037	2989	5306	4000	2956	1044	1579	3353	483	254	4492	4286	1025	1358	**33124**
2038	3023	5338	4097	3028	1068	1617	3435	494	258	4594	4384	1037	1392	**33765**
2039	3052	5403	4175	3097	1088	1656	3519	506	262	4696	4473	1051	1425	**34403**
2040	3085	5438	4273	3163	1114	1697	3604	518	267	4799	4569	1067	1460	**35053**