Lappeenranta University of Technology

School of Business and Management

Industrial Engineering and Management

Global Management of Innovation and Technology

Olga Vokueva

MODEL-BASED UNIVERSITY MANAGEMENT: SYSTEM DYNAMICS APPROACH

Master's Thesis

2017

Examiners: Leonid Chechurin

Samuli Kortelainen

ABSTRACT

Olga Vokueva

Model-based university management: System Dynamics approach

Lappeenranta University of Technology

School of Business and Management

Industrial Engineering and Management

Global Management of Innovation and Technology

2017

Master’s Thesis

74 pages, 29 figures, 7 tables, 4 appendices

Examiners: Leonid Chechurin

Samuli Kortelainen

The complex structure of university provides challenges to university management in terms of tracing the consequences of its decisions. Model-based university management allows examining the system holistically and revealing the underlying trends in the system’s behavior. System Dynamics is one of the most promising tools to support decision-making in higher education institutions as the structure of university appears to be non-linear and dynamic. The goal of the current study is to propose a predictive model showing the effects of a certain managerial decision, in this case, the number of professors in a university. By conducting the literature review and defining the theoretical framework for the research, the System Dynamics model were created using Vensim software. The model is able to forecast the number of graduate students and the amount of scientific publications in response to the changes in the quantity of the teaching staff.

Keywords: university management, modelling, System Dynamics, university system, model-based management, decision-making

ACKNOWLEDGEMENTS

I would like to thank Professor Leonid Chechurin for the advice during my work on the thesis. I also would like to acknowledge Petri Hautaniemi and Sirpa Riikkinen at Lappeenranta University of Technology who provided valuable comments and information needed for the thesis. Most of all, I would like to express my gratitude to my family and, especially, my mother and my soulmate for the continuous encouragement throughout my years of study. My mother was also the most supporting person during the process of writing the thesis. All my accomplishments would not have been possible without you. Thank you.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

BOS – Boards of Studies

BSC – The Balanced Scorecard

CRM – Customer Relationship Management

DSS – Decision Support System

FCE – Fuzzy Comprehensive Evaluation

FGP – Fuzzy Goal Programming

FTF – Full-time Faculty

GA – Genetic Algorithm

KPI – Key Performance Indicator

LUT – Lappeenranta University of Technology

SCM – Supply Chain Management

SEM – Structural Equation Modelling

SD – System Dynamics

SLR – Systematic Literature Review

TQM – Total Quality Management

VSM – Viable System Model

1 INTRODUCTION

1.1 Background

It is generally believed that university's core activities are providing high-quality education and conducting researches. Appropriate management strategies are able to ensure the effective performance of higher education institutions. Since university appears to be a complex social system (Galbraith, 1999), it is argued that there are considerable challenges in its managing. The system seems to be non-linear and, thereby, it becomes difficult to predict the implications of applied managerial policies in the future. The system thinking approach could serve as a method to support decision-making processes in higher education (Galbraith, 1999).

There is a variety of studies devoted to university's decision-making processes and policies. However, dynamic model-based approach to university management seems to be paid less attention, especially, in a real life where policy-makers normally use linear statistical tools and models (Kennedy, 2000). The interest in System Dynamics (SD) modelling in higher education has been constantly growing; however, there is no unified and accurate model for the university system.

The given research attempts to take the first step in modelling university system with the first level of approximation. It focuses on the challenge of making appropriate managerial decisions in terms of teaching staff, as well as forecasting the implications of those decisions. There are number of studies devoted to predicting either graduation rate or research productivity of a university. In this research both factors are under the study.

1.2 Research questions and limitations

The main goal of the study is to create a scenario model for university management used to predict the consequences of certain managerial decisions. The proposed system must be able to forecast the outcomes of the university system when the control parameter is changed. The given research focuses on management decisions in terms of human resource management. It studies the relationship between the number of professors in a university and its products. The terms "university's products" or "university's outcome" denote the two main factors characterizing the end-products of higher education institution that are the quantity of graduate students and the amount of scientific publications. Overall, the proposed model is expected to support decision-making processes in universities. System Dynamics approach acts as a basis for the modelling, however, the other modelling methods are reviewed in order to show the possible ways to solve the given issue. The simulation of the model is based on data provided by Lappeenranta University of Technology, and some data have to be imitated in order to run the simulation.

Hence, the two research questions can be outlined that are the following:

RQ1: What is the most efficient framework to develop predictive model in terms of studying the dependence between professors, students, and research in a university?

RQ2: How the number of academics in a university influences the number of graduates and research papers produced by this institution?

In order to answer the research questions, the following objectives must be achieved: (1) to investigate already existing models devoted to model-based university management; (2) to determine the most suitable model technique to predict the results of managerial decisions in a university; (3) to extract the ideas from the reviewed studies which are the most suitable for answering the research questions; (4) to develop the model; (5) to perform the simulation using the data provided by LUT; (5) to obtain the results and propose the ideas for future research.

As for the limitations, the purpose of the study is to give a general insight into the stated problem. Since university is a large complex system, it contains a multitude of elements and relationships that can be sometimes underlying. In the current study, the first level of approximation is presented. The further expansion of the model is required to achieve the most accurate results. In addition, most of the coefficients and parameters in the model are imitated, since, unfortunately, the data inquired from Lappeenranta University of Technology are inconsistent and do not meet the requirements of the study.

1.3 Methodology and thesis structure

Quantitative research method is used as a methodology in the current study. This is a correlation research aiming at examining statistically the relationship between several factors with an attempt to forecast their possible behaviors. Firstly, by conducting the systematic literature review as a secondary research, the appropriate theoretical framework have been defined. Secondly, the linear regression analysis is performed in order to trace the correlation between two parameters in the system. Finally, System Dynamics approach is applied for the modelling of university system. The part of the statistical data requested from Lappeenranta University of Technology are served as a secondary source of information. Some of the data have to be imitated in order to run the model.

The structure of the thesis is as follows. The thesis is divided into three chapters. The first chapter is the literature review where the most recent and relevant theoretical university models are observed. In addition, there is an explanation of System Dynamics approach. The second chapter is devoted to the modelling of university system to examine the relationship between the number of professors and the university's outcome. In the third chapter the discussions are provided together with the future implications.

2 PREVIOUS STUDIES ON MODELLING UNIVERSITY MANAGEMENT

2.1 Selection of the review papers

A systematic literature review (SLR) on model-based approaches to university management was applied as the research strategy in the study. The main objective of the review is to identify the state of the art of the researches related to the assessment of university performance by means of modelling institutional behavior. The research aims to define what has been already done in this field and to show the growing interest in model-based approaches in university management or, on the contrary, to reveal that few studies were dedicated to the issue. The conduction of the systematic literature review in the study was based on the guidelines provided by Kitchenham (2004) who proposed a search strategy that includes three stages: planning, conducting, and reporting the review. Adherence to this strategy allows a researcher to perform a comprehensive analysis of the literature devoted to a specific issue (Kitchenham, 2004).

2.1.1 Planning the systematic literature review

The first step of planning the review is to create the review protocol and formulate resview questions in order to clarify the objectives of the literature study and outline the criteria for the selection process (Kitchenham, 2004). Accordingly, the review protocol was developed and research questions were identified. A tentative search was conducted before the setting of the strategy in April 2017. As a result, several databases were selected for the systematic search as they have the most significant amount of publications on the related issue. In addition, key search words were formulated based on the completeness of the sources they provided.

As it was mentioned before, the main purpose of the literature review is to find the applications of model-based assessment of management in higher education. The following review questions were developed.

RQ: How modelling is applied to university management?

RQ1: What kind of modelling is applied: qualitative or quantitative, static or dynamic?

RQ2: What kind of problems models of the university system solve?

RQ3: What is the focus of the selected models: finance, quality, number of students, or the other ones?

There are three digital libraries chosen for the selection process: ProQuest ABI/INFORM Collection, Scopus, and IEEE Xplore Digital Library. A tentative search was performed by using such keywords as “modeling”, “university”, and “management”. Additional keywords “modelling”, “modeling”, “model-based”, “system”, “higher education”, “assessment” were used as synonyms and added to the query using OR operator. Only scholarly journals and conference paper and proceedings in English were chosen as sources in order to eliminate irrelevant publications. As for document type, articles and case studies were the search options. The experimental search in ProQuest ABI/INFORM Collection revealed that the interest in modelling of university behavior has increased between years 2010 and 2017 (fig. 1). Therefore, the given date range was included in the final search query. The final search queries for the each library are presented in the table 1.

Table 1. The search queries for the chosen databases

The name of the database	The search query
ProQuest ABI/INFORM Collection	all(modeling) AND all(university) AND all(management)
Scopus	(TITLE-ABS (modeling) AND TITLE (university) AND TITLE-ABS (management)) AND (LIMIT-TO (SRCTYPE , "j ") OR LIMIT-TO (SRCTYPE , "p ")) AND (LIMIT-TO (DOCTYPE , "ar ") OR LIMIT-TO (DOCTYPE , "cp ")) AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "COMP ") OR LIMIT-TO (SUBJAREA , "ENGI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "MATH ")) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (

	PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 2001) OR LIMIT-TO (PUBYEAR , 2000)) AND (LIMIT-TO (LANGUAGE , "English "))
IEEE Xplore Digital Library	(((model) AND "Document Title":university) AND management) and refined by Year: 2000-2017

Since Scopus digital library provides more sophisticated search options and analytics, it allows narrowing to the most relevant studies and sorting them by the amount of citations of the sources. The publications were limited to those with the subjects of Economics, Business and Management, Computer Science, and Mathematics. As it can be seen in the figure 2, studies of model-based university management have experienced a dramatic increase in 2016.

In addition, in order to study thoroughly the application of modelling in the institution management, a few articles in Russian were added to the review list. The publications were found through the Russian universities' web-pages: National Research University Higher School of Economics (Publications of HSE, 2017) and Volgograd State University (MEPS VSU, 2017).

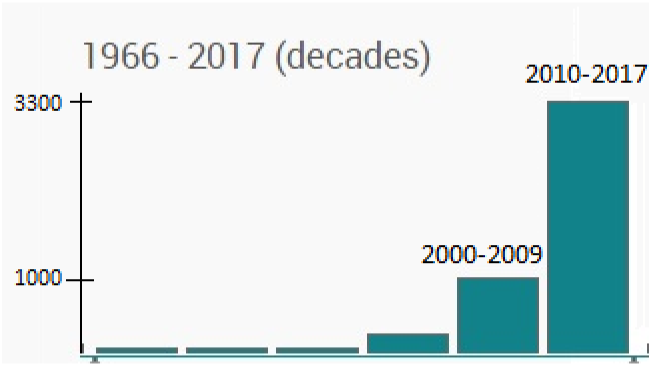


Figure 1. Years of growth in the publications related to model-based university management according to ProQuest ABI/INFORM Collection

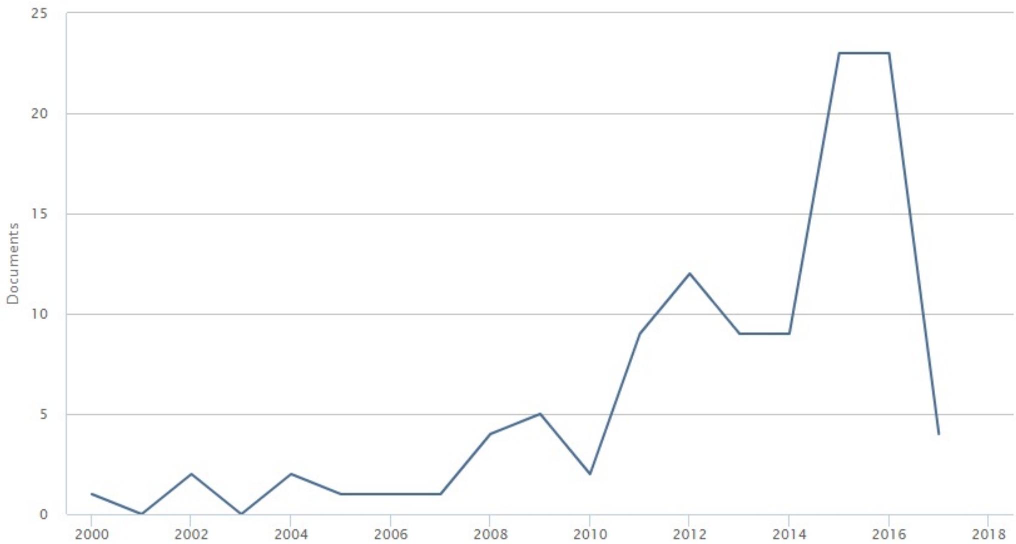


Figure 2. Analysis of search results provided by Scopus: documents by years

2.1.2 Conducting SLR

A table 2 provides the total amount of publications obtained by performing the systematic search in the digital libraries.

Table 2. The results of the search queries

The name of the database	The number of publications
ProQuest ABI/INFORM Collection	395
Scopus	108
IEEE Xplore Digital Library	558

For the sake of the relevance, a scope of the studies was restricted to primary studies of specific types with full text available, which contain either mathematical models or proposed ontologies for university system. The publications included in the review list were selected in accordance with predefined review questions. First of all, the title of a publication served as the main criterion of the selection since many of the studies were devoted to physical modelling unassociated with the current research. However, this could not be avoided by more sophisticated search query due to the risk of neglecting relevant studies. Secondly, abstracts and methodologies of the preselected papers were considered. Thereby, SLR was performed using the following search criteria, mentioned in Kitchenham's report as "inclusion criteria" (Kitchenham, 2004):

- The context of modelling management practices in universities;
- The presence of either quantitative or qualitative models of university system;
- Full text available;
- Appropriateness to the review questions.

After screening the abstracts, full texts and references of the papers, the final list of articles to be reviewed has been created. There are 22 articles found by applying systematic search in the digital libraries involving the ones discovered by screening through the articles' reference lists. In addition, one article founded in LUT Finna appealed to be useful for the research and has been added to the list. Overall, 26 articles comprised the list of literature for the review including two scientific works in Russian, described previously. The search results are illustrated in the table 2, and the flow diagram depicting the selection process is presented in the figure 3.

Table 2. Search results

The name of the source	Number of publications
ProQuest ABI/INFORM Collection	7
Scopus	2
IEEE Xplore Digital Library	14
Other sources	3

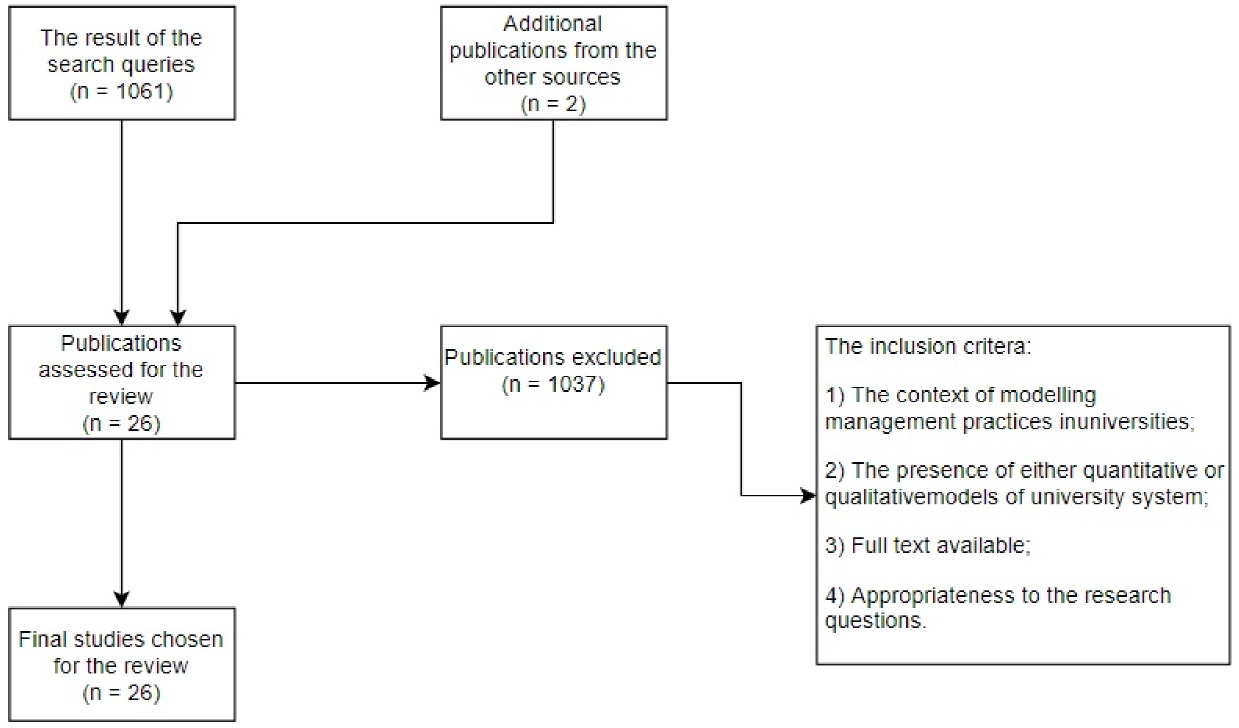


Figure 3. Flow diagram representing the selection of the studies

2.1.3 Reporting the review

The selected articles were divided by the type of modelling they described. There are three main divisions that have been extracted from the reviewed documents. System Dynamics modelling appears to be one of the emerging trends of modelling university system. About one third of the chosen publications or eight articles, to be precise, are devoted to this issue. The rest of the studies encompass static models, as well as dynamic ones, however, they do not apply SD modelling method as it was introduced by Forrester (1961). The other methods that gave the impression of being widely used in such cases are Structural Equation Modelling (SEM) and methods referred to fuzzy logic. There are three articles dedicated to SEM and four – to fuzzy methods, respectively. In addition, decision tree rules, entropy evaluation method are used as modelling techniques. The implication of the studies and their areas of focus will be described in the summary of the review below.

2.2 The application of modelling to university management

One of the biggest challenges in university management appears to be the allocation of financial and human resources between different university activities, particularly, between teaching and research. When it comes to budget uncertainty, the issue of optimal allocation can become crucial since an institution wants to produce sufficient amount of graduates and, at the same time, maintain high-quality research output. According to Rybnicek (2015), external instructions to the distribution of resources do not correlate with goal-oriented internal strategy of university. Consequently, universities are provided with much freedom in terms of resource usage and, thus, university management faces difficulties in finding the optimal solution to the issue (Rybnicek, 2015).

Most of the reviewed articles have a common purpose that is to offer the best strategy for university development in terms of resource allocation, both tangible and intangible. On the other side, the rest of the papers focuses on performance assessment of university management. In order to address those issues, different approaches were applied. The conducted literature review provides an information about the most applicable modelling techniques used in the context of higher education.

2.2.1 System Dynamics in modelling university performance

According to Hawari and Tahar (2015), System Dynamics stands among the most useful tools for long-term planning in institutions of higher education. In their study, the authors combined the balanced scorecard (BSC) and System Dynamics approaches and developed a decision support tool for university administration. SD appears to be the most appropriate method to handle such complex and continuously changing system as university. Hawari and Tahar (2015) stated that applying SD approach allows to analyze a university system holistically and to reveal underlying trends that cannot be easily discovered by common statistical methods. The main reason for inefficiency of common planning tools, such as, for instance, key performance indicator (KPI) method, is their inability to trace processes inside the system and their influences as they consider only inputs and outputs of the system (Hawari and Tahar, 2015).

In short, the balanced scorecard is used to transform the goals of an organization into key indicators in the form of outputs of the system. The theory is based on believe that the effectiveness of the system's internal functioning depends on reaching specific targets set by management. However, the balanced scorecard, being a static method, does not contain the feedback loops and, consequently, is not able to identify an impact of the outputs on the systems' internal processes. By mixing SD and BCS, the authors analyzed 5-year data from Malaysian university and, having defined KPIs, identified dynamic behaviors using SD approach. The results were organized into the causal loop diagram (fig. 4) and, subsequently, into the stock and flow diagram for the final SD simulation. The stages of the modelling process are illustrated in the figure 5 (Hawari and Tahar, 2015).

Overall, Hawari and Tahar (2015) have developed the model that shows how different policies affect university's performance indicators in the four perspectives used in BSC analysis: Learning and Growth; Financial; Customer; and Internal Process. The model is aimed to facilitate decision-making process at universities, and it has proved its effectiveness in the real case of the Malaysian university (Hawari and Tahar, 2015).

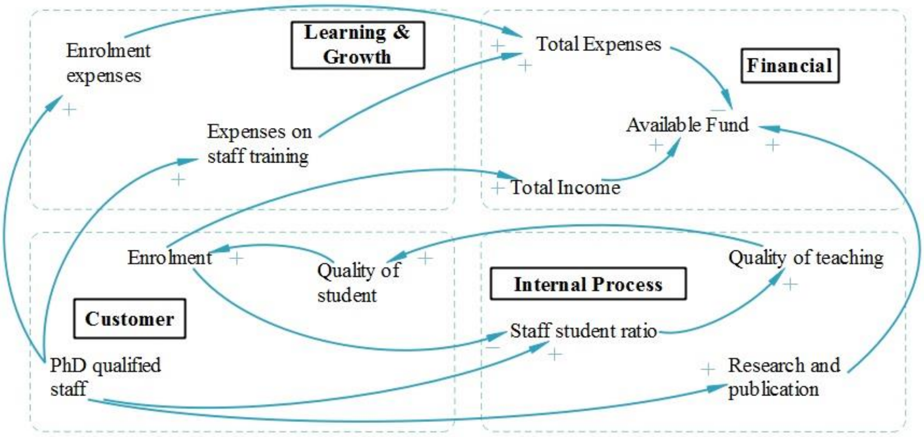


Figure 4. The causal loop diagram (Hawari and Tahar, 2015)

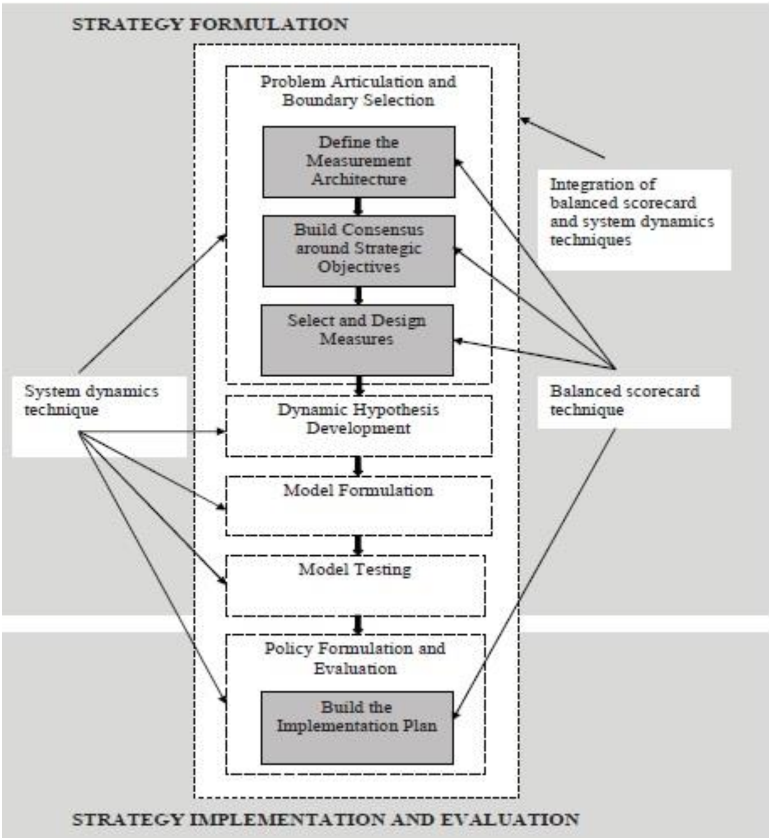


Figure 5. Application of System Dynamics and the Balance Scorecard approaches in university planning (Hawari and Tahar, 2015)

Dahlan and Yahaya (2010) focused on the more specific issue connected to university management. The authors used SD approach to build a decision support system (DSS) for the evaluation of university's educational capacity and effective resource allocation. It is also argued that methods based on KPIs can neither trace the influences between the changes nor produce the forecast. Thus, the authors employed SD in their decision support model that focused on calculating the optimal admission capacity in parallel with sustaining the required quality of education. The supply and demand model was developed based on the academic structure of the Malaysian university. This model was supplemented with supply and demand equations to balance resource distribution. In order to add dynamic properties, the stock and flow diagram was introduced. The diagram encompasses central quality characteristics in addition with supply and demand indicators, such as number of enrolled students (fig. 6). Overall, instead of using data for several years from data warehouses, the authors simulate the developed dynamic model iteratively using only the input data provided by the university (Dahlan and Yahaya, 2010).

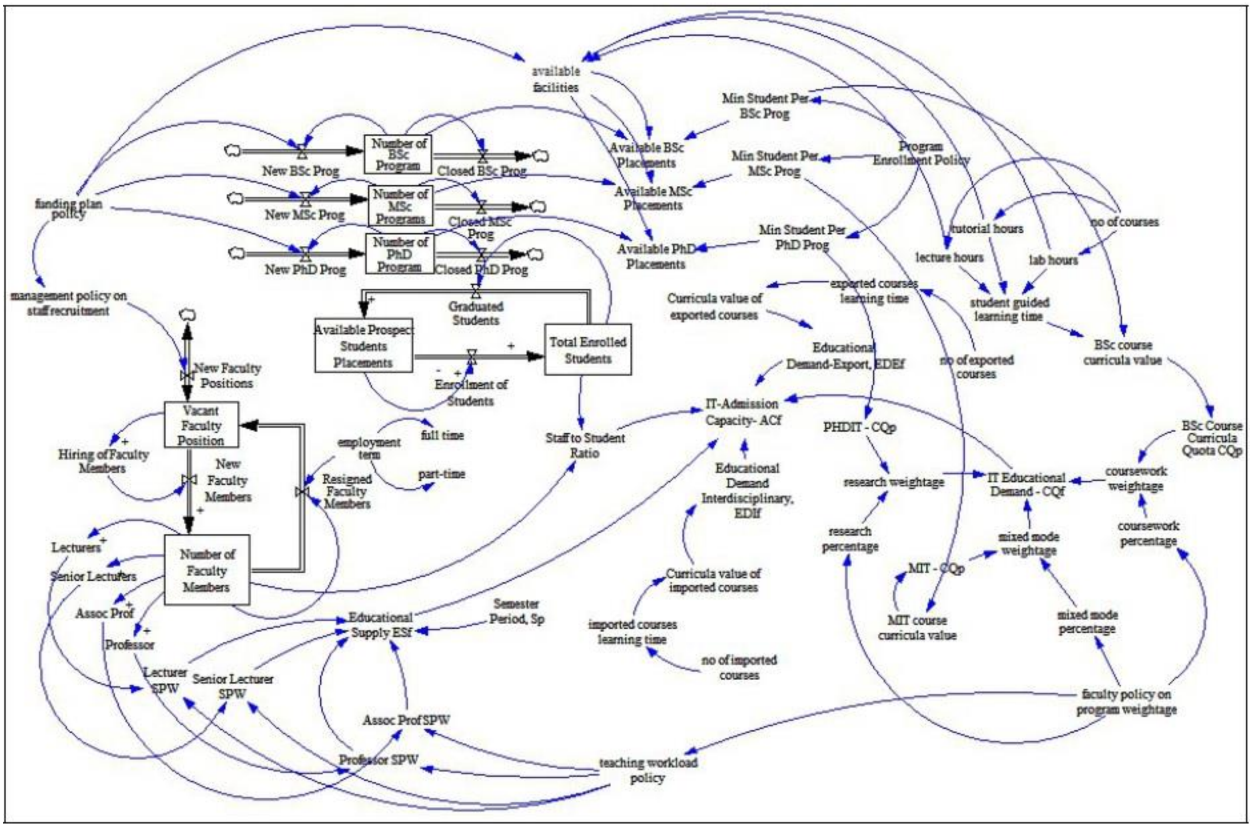


Figure 6. The stock and flow diagram of DSS for university resource allocation (Dahlan and Yahaya, 2010)

Robledo, Sepulveda and Archer (2013) considered the application of SD in forecasting enrollment and retention rates at university level, as well as at department level, and designed DSS that allows effective resource allocation management. The authors proposed a hybrid model by applying SD approach for the top-down modelling at university level integrated with Agent-based simulation for the bottom-down modelling at department level, respectively. Such approach provides the more detailed insight of university system and allows studying the factors affecting enrollment and retention processes not only at the general level but also in the university faculties (Robledo, Sepulveda and Archer, 2013).

Initially, according to the model, students are signed to different cohorts and traced during their education. The SD diagram is presented in the figure 7 and shows the students' enrollment process as the transition of the cohorts through the states (freshman, sophomore and so on). The resource allocation is ensured by introducing "batches of students" that will be distributed among different faculties, classrooms and, for instance, labs (Robledo, Sepulveda and Archer, 2013, 2072). As for the bottom-up approach, using Agent-based simulation, the authors considered only one department and focused on forecasting the required number of labs, classrooms or parking lots for the next year from the department's point of view. The authors argued that the multi-level simulation could reveal new factors influencing university behavior, and these factors could potentially improve resource management and decision-making processes at universities (Robledo, Sepulveda and Archer, 2013).

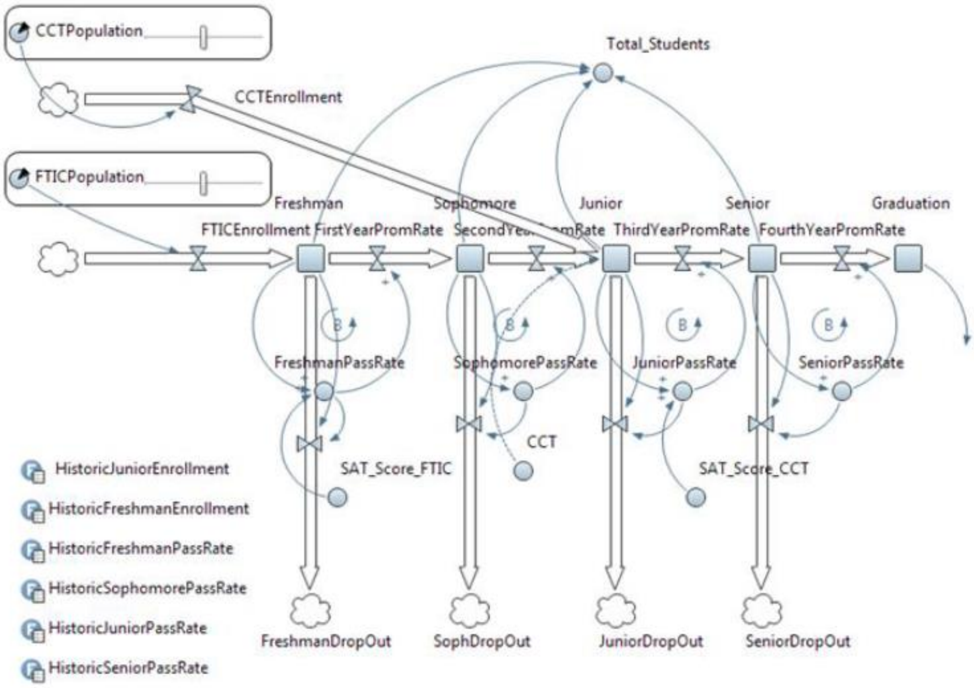


Figure 7. Stock and flow diagram for the high-level modelling of enrollment process using SD approach (Robledo, Sepulveda and Archer, 2013)

The other study employing System Dynamics is provided by Rodrigues et al. (2012). The authors introduced a model to facilitate universities in strategic planning. The model focuses on quality characteristics and their enhancement. The main objective is to identify factors that influence the quality of university services. The quality characteristics in the example are determined by ABET (Accreditation Board of Engineering and Technology) criteria and composed of eight aspects. A figure 8 depicts the structure of Total Quality Management (TQM) system based on the given criteria. Dynamic approach injects delays in providing these quality standards and enables modelling of university's strategy to achieve its quality goals (Rodrigues et al., 2012).

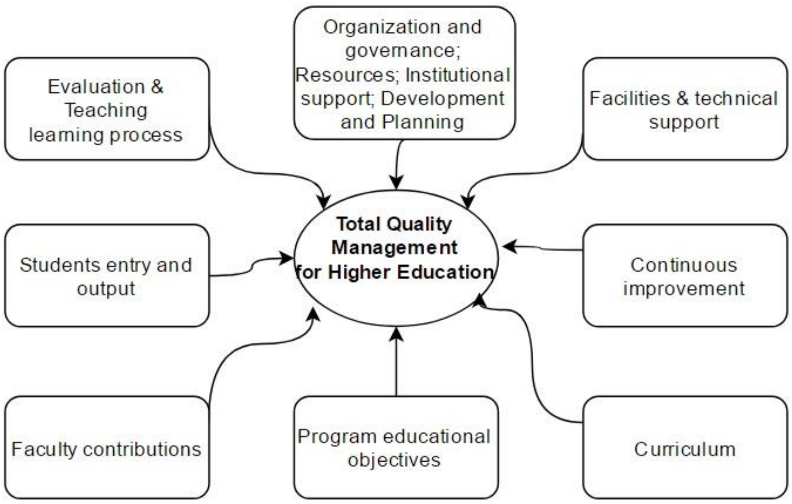


Figure 8. Total Quality Management system for higher education (Rodrigues et al., 2012)

As the result, the system identifies the number of years needed to achieve the required service quality. The quality of university performance is represented by TQM index calculated through point-based assessment on the given eight measurements. The authors designed stock and flow diagram for the TQM index including the rate of its adoption illustrated on the figure 9 and figure 10 (Rodrigues et al., 2012).

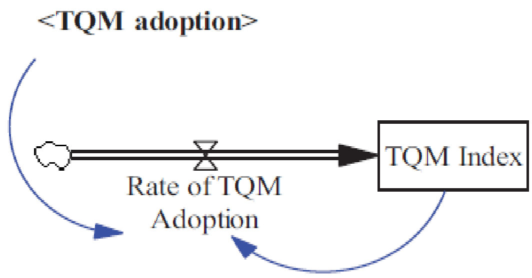


Figure 9. Stock and flow diagram for TQM index (Rodrigues et al., 2012)

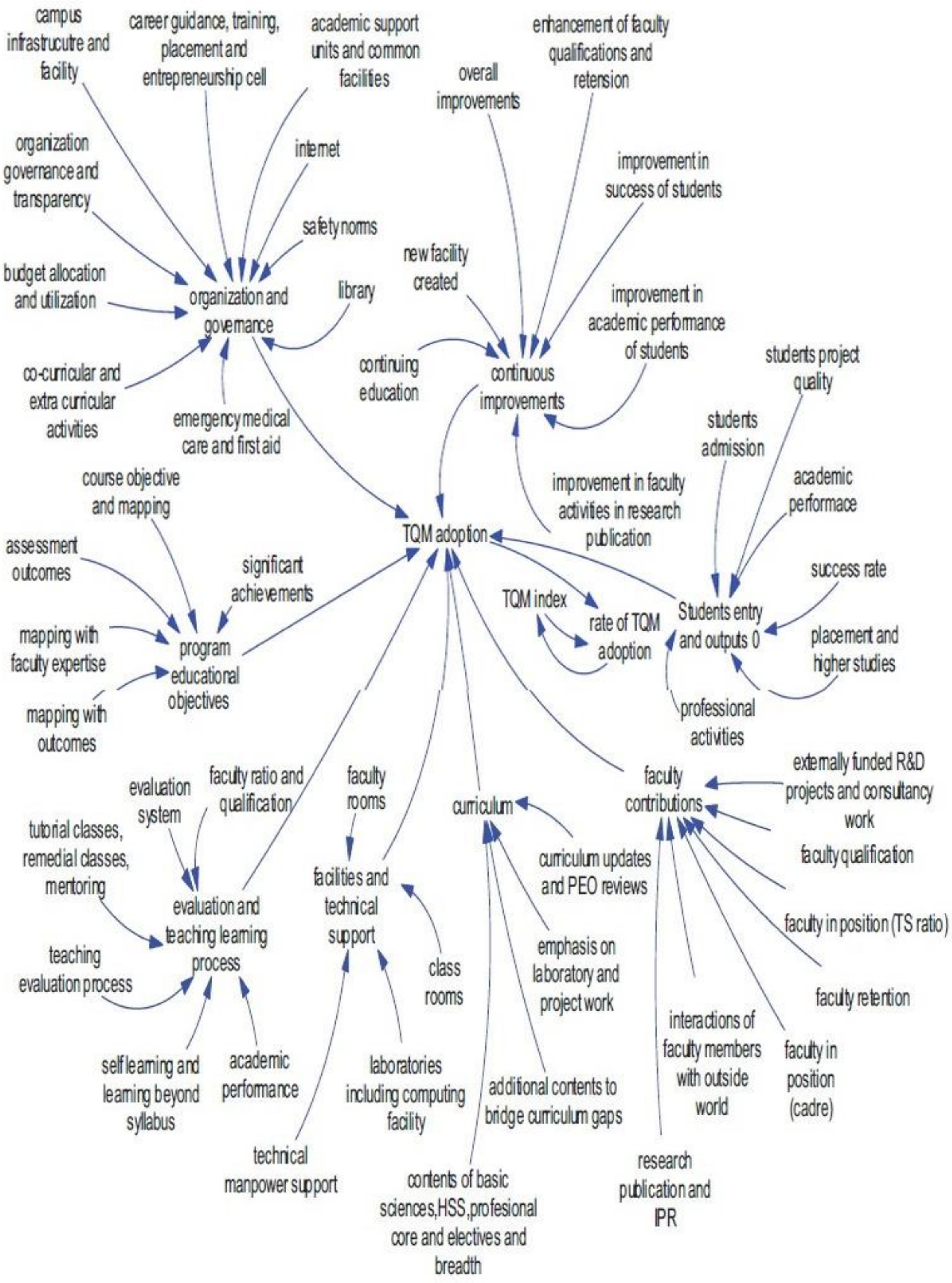


Figure 10. Stock and flow diagram for university system (Rodrigues et al., 2012)

System dynamics has been used not only in DSSs for strategic planning and resource allocation but also for Customer Relationship Management (CRM). Bing, Yuan and Yuan (2009) proposed a model that is able to forecast the results of university's projects related to its CRM. First of all, the authors defined university customers by dividing them into two categories: external and internal. External customers include students and their parents, as well as investors and employers. Internal ones are the university's staff being an intangible asset of an institution. While university provides its services to students and their parents, graduate students appears to be the products that university offers to employers. The system designed by Bing, Yuan and Yuan (2009) combines four interrelated subsystems presenting students, employers, teachers, and investors. In order to show the relationship between the subsystems and their effects on CRM decision-making, the authors created a causal relationship diagram illustrated on the figure 11. According to the article, after the simulation, the model predicted the best portfolio programme for increasing customer satisfaction or, in other words, the model showed university management which factors must be improved and by what means in order to enhance its CRM (Bing, Yuan and Yuan, 2009).

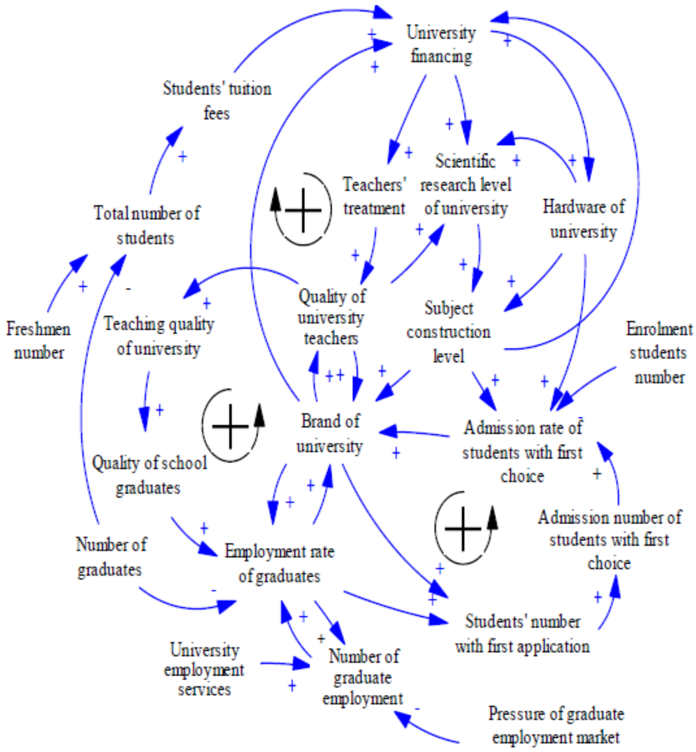


Figure 11. Causal relationship diagram of the CRM decision-making mechanism in university (Bing, Yuan and Yuan, 2009)

Dandagi et al. (2016) suggested another dynamic model for university governance using structural equation modelling (SEM). Variables and the causal relationship between the components of the model were identified by questionnaires and were applied in the context of technical university (fig. 12). On this basis, structural equation model was developed including the given factors and arrows with the depicted path coefficients (the regression coefficients) defining their significance (fig. 13) (Dandagi et al., 2016).

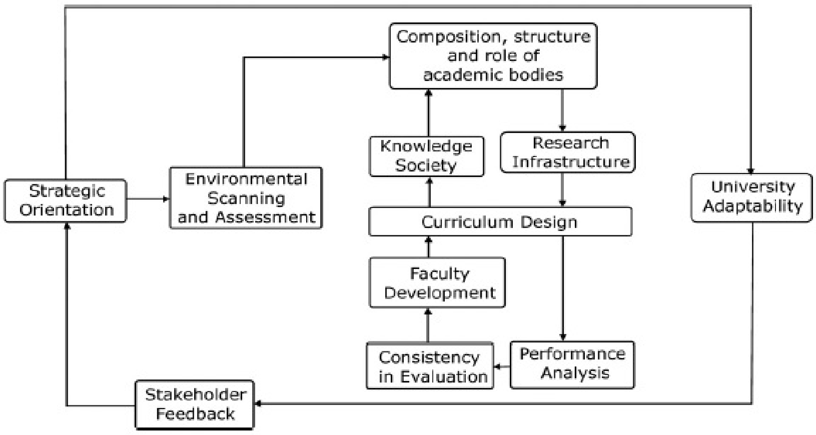


Figure 12. Factors affecting technical university management (Dandagi et al., 2016)

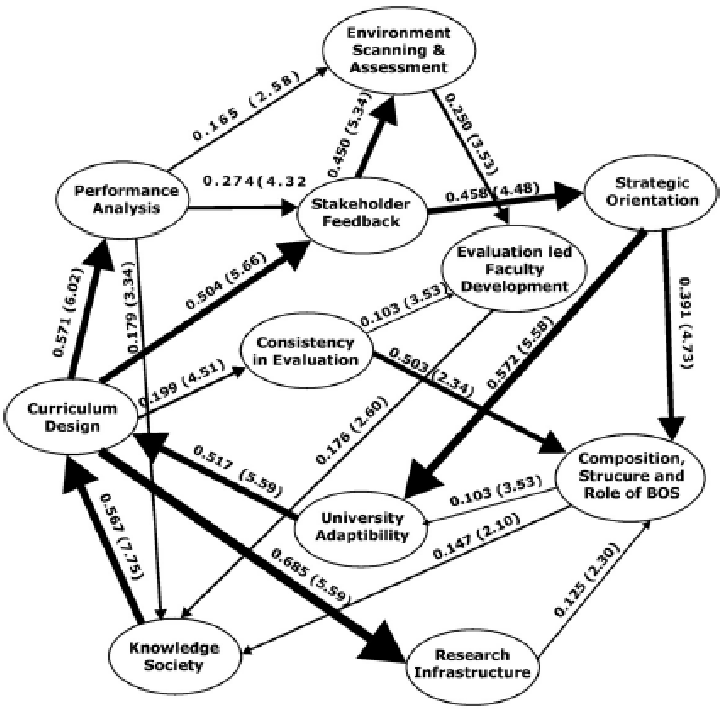


Figure 13. Structural equation model for technical university's strategic governance (Dandagi et al., 2016)

Three important causal loops were noticed from the SEM. As an example, one of the loops is positive and shows that strategic orientation of technical university affects stakeholder feedback in a positive way through having an impact on the role of academic bodies such as Boards of Studies (BOS) which, respectively, improve university's adaptability resulting in well-designed curriculum. The loop is illustrated in the figure 14 (Dandagi et al., 2016). The system was simulated using SD in order to reveal dynamic behaviors of the variables. One of the interesting outcomes obtained was, for instance, the conclusion that university's adaptability to dynamic environment is influenced by its strategic orientation (Dandagi et al., 2016).

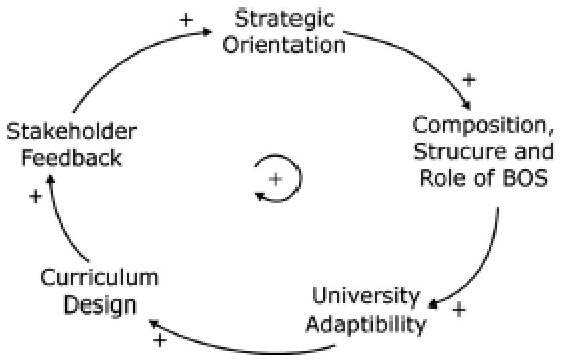


Figure 14. The causal loop showing the influence of university's strategic orientation on stakeholder feedback (Dandagi et al., 2016)

Sababi Pour Asl and Bafandeh Zendeh (2014) also applied SD approach to facilitate university planning; however, they created a model that predicts the amount of bachelors, masters and PhD degree students for the upcoming years for the Iranian university. As a result, the authors discovered the key characteristics that influence student demand on different levels. First, they identified variables affecting the behavior of student demand and interactions between them, then the stock and flow diagram was built and the model was simulated. The result showed the predictions for the number of BA, MA and PhD students in the future (Sababi Pour Asl and Bafandeh Zendeh, 2014).

Galbraith (2010) studied the usage of SD in modelling university management at general level. The author introduced a typical institutional structure. In the article, it is also stated that SD is able to show the consequences of the short-term decisions in the long run (Galbraith, 2010).

Finally, Barlas and Diker (2000) in their research developed a dynamic model to address such issues related to university government as “growing student-faculty ratios, poor teaching quality and low research productivity” (Barlas and Diker, 2000, 331). The model also supports strategic decision-making in universities. An interactive game was created based on that model. The players were faculty members with different backgrounds and degrees. The authors studied the differences between decisions of several types of players, for example, “research-oriented” and “balanced” faculty members, and the outcomes of their strategies. Overall, the model also helps to understand the complex structure of university and support solving of main managerial issues in higher education (Barlas and Diker, 2000).

After examining the below mentioned models, one can draw a conclusion that all of them appear to have one common feature that is the focus on forecasting system conditions and identification of actions that led to those conditions. Since SD approach was the most popular modelling technique in the given review, it was decided to divide all articles in three categories. The following two chapters encompass all qualitative and quantitative models that are not related to SD approach.

2.2.2 Qualitative models

According to Matsuo and Fujimoto (2008), assessment of university’s performance is usually done by means of measuring numerical indicators of the effectiveness, such as costs, investments and cash flow. The authors proposed a qualitative model to support planning at small and medium-sized universities. The model is based on the concept of non-financial decision-making, for example, examining statuses of university operations, and it is able to recognize an efficient operation. The method described in the article is similar to System Dynamics in terms of studying dynamic environment; however, the authors applied qualitative approach avoiding using formulas and operating only with causal relationships and qualitative values. A causal graph was chosen as a basis on the model. It consists of nodes and arcs, the qualitative values of the nodes are defined as [+], [-], and [0]. Arcs describe the changes in the qualitative values through time and have three trends: increasing, decreasing, and stable. The interconnections of values and their influences on each other's states are also considered, and a transmission speed as a delay in changing is introduced (Matsuo and Fujimoto, 2008).

Habib and Jungthirapanich (2009) introduced a conceptual model for educational management where a university was considered as a service provider having its supply chain. Supply Chain Management (SCM) at university is comprised of three decision levels: the first level is strategic for long-term goals; the second level is planning one for the shorter terms; and the third level is operating one for short-term objectives. According to the article, the university SCM is divided into two dimensions connected to education and research. The authors suggested educational SCM model for university that encompasses all university stakeholders. The model includes the three previously defined decision levels based on the supply chain for higher education presented on the figure 15. The number of graduate students with recommendable quality and the research outcomes determine the system output. In addition, four characteristics of university that influence its SCM were introduced that are programs establishment, university culture, faculty capabilities, and facilities (Habib and Jungthirapanich, 2009). In the following chapter, the given conceptual model was evaluated quantitatively (Habib and Jungthirapnaich, 2010a).

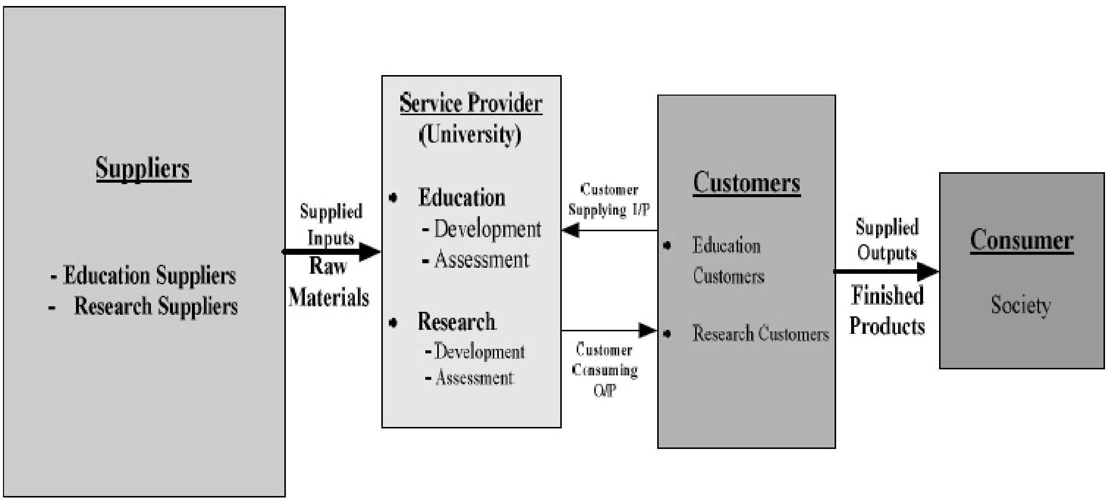


Figure 15. Supply Chain Management for higher education. (Habib and Jungthirapanich, 2009)

Another qualitative method of modelling university's behavior was suggested by Adham et al. (2015). Rather than concentrating on the organization's particular functions, such as teaching and research, the authors examined university structure from the perspective of system thinking. Viable system model (VSM) was chosen as the framework for the research. The proposed system encompasses not only major higher education functions as teaching and research, but also the ones that allow a university to sustain its viability, for example, coordination between the subsystems or commercialisation. The main benefit provided by system thinking approach is an opportunity to study the complex university structure holistically and define the role of university administration (Adham et al., 2015).

As can be seen, the three qualitative models are focusing on assessing the structure of an institution. Avoiding financial decision-making, the models are aimed to describe the system holistically and examine university's operations at general level.

2.2.3 Quantitative models

Borooah (1994) examined the selection of an effective teaching-research combination made by university departments. The author stated that, providing finances to the institutions, governments are mostly interested in three outputs in order to assess how properly they are used, which constitute the main aspects of the authors' model: finance, efficiency and quality. Borooah (1994) attempted to simulate and analyze the most effective operation of an academic department. The model is drawn upon the assumption that there are two products of department's activity – students and research; each of them refers to the corresponding production function. Teaching and research are perceived as competitive practices since they both require resources that are limited due to the budget and quality constraints. As for the outputs, department's teaching output is evaluated by the number of graduate students, N, and its research output – by the value R, which, for instance, can be measured as the annual amount of academic publications (Borooah, 1994).

In order to define the department's production function, two types of academics were introduced: (1) R-type academics that tend to devote their time mainly to research and (2) N-type ones focusing mostly on teaching. Borooah proposed the equations for the number of academics of each type presented below as (1), (2), (3):

$$L_R = L\theta \tag{1}$$

$$L_N = L(1-\theta) \tag{2}$$

$$0 \le \theta \le 1. \tag{3}$$

In order to simplify the model, the author assumed that the input number of students accepted to a department is equal to the output number of graduates. The second assumption is that both types of academics work the same number of hours, h, per year. Since each lecturer can be engaged in both research and teaching, two coefficients were introduced. In accordance to the model, R-type lecturer dedicates α proportion of time to research activities and (1 - α) – to teaching ($0 \le \alpha \le 1$). Respectively, β is the allotment of time to research for N-type lecturer, while he spends (1 - β) proportion of time on teaching ($0 \le \beta \le 1$).

$$R = R\{hL\theta\alpha, hL(1-\theta)\beta\} \tag{4}$$

$$N = N\{hL\theta(1-\alpha), hL(1-\theta)(1-\beta)\} \tag{5}$$

It is supposed that $\alpha > \beta$. Thereby, having the amount of hours on the corresponding activity for each type of academics as an argument, the production functions for research and teaching, are shown in (4, 5). Having analyzed the model, the author concluded that in order to ensure the maximum research output and the required number of graduates, the solution is attaching of R-type lecturers to research only, if the effectiveness of teaching is sufficient, and, respectively, N-type ones to teaching only. Thus, $\beta = 0$ and $\alpha \le 1$ considering the fulfillment of teaching needs that can be solved by R-type lecturers' contribution to it (Borooah, 1994).

Casper and Henry (2001) have developed a model supporting effective resource allocation and focusing on expenditures and university's equipment distribution between its departments. For the equipment allocation "the relative equipment intensity" (most intensive, moderate intensive, and least intensive) for each department was defined (Casper and Henry, 2001, 356). Besides, two variables for performance assessment of the departments were considered: full-time equated students (FTES) and full-time equated faculty (FTEF).

The authors generated a formula for the preliminary equipment allocation for each university unit that involved funds (A), the relative equipment intensity (λ), relative weights describing the percentage of full-time faculties or students (α and β), and, finally, a coefficient μ as a balancing factor to ensure the availability of funds:

$$PFA = A*\lambda*\mu*\{\alpha*[(FTEF) / (\Sigma FTEF)] + \beta*[(FTES) / (\Sigma FTES)]\}. \qquad (6)$$

Similar approach was applied to develop a formula for current expenditures of the faculties (Casper and Henry, 2001).

Boronico, Murdy and Kong (2014) also mathematically addressed the issue of effective resource allocation in university. The authors utilized linear programming model to assess university capacity allocation in terms of full-time faculty members. By leveraging the mathematical model based on optimization equations, universities are able to maintain flexible allocation plan and effectively meet faculty requirements (Boronico, Murdy and Kong, 2014).

Habib and Jungthirapnaich (2010a) treat university management as a supply chain system there the transformation of data to wisdom takes place (fig. 16). Knowledge is converted into wisdom by means of education, and proper academic management is the key to successful transformation. The purpose of the study is to develop a model for integrated university management that supports the relations between university and its stakeholders, for example, companies or schools (Habib and Jungthirapnaich, 2010a).

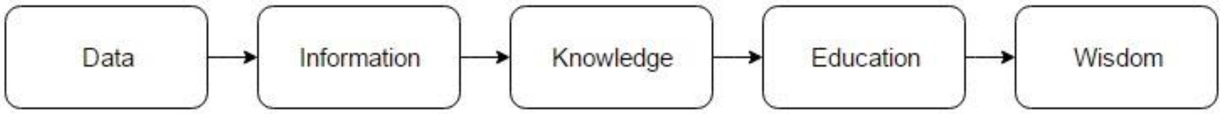


Figure 16. The transformation of data to wisdom (Habib and Jungthirapnaich, 2010a)

Two key factors of successful educational management were derived in the research: number of graduates with appropriate quality and the quality of research outcomes. Number of university's current students and number of research projects are taken as the inputs of the system. In order to evaluate the factors influencing assessment and development of two academic activities such as education and research, Structural Equation Modelling was performed through questionnaires and statistical tools. As for the first outcome, graduates, SEM revealed that "programs establishment, university culture, faculty capabilities, facilities affect significantly the education development and education assessment to produce graduates" (Habib and Jungthirapnaich, 2010a, 3). The structural equations for studying the research outcome also showed that all proposed factors (university culture, facilities, program establishment, and capabilities of faculties) affected development and assessment of research activity in universities. Interestingly, the authors stated that the major factor influencing the number of graduates, as well as research output, is university culture. (Habib and Jungthirapnaich, 2010a) The authors expanded their research on SCM for universities by studying key stakeholders for university's supply chain (Habib and Jungthirapanich, 2010b). Having applied multiple linear regression (MLR) and structural equation modelling techniques, they identified the components having an impact on university's performance. There are two types of suppliers and customers: education and research ones. Education suppliers are presented, for instance, by private funding organizations, government or high schools providing students. Ministry of education can serve as an example of research supplier. On the other side, education customers include families and employers, while research customers are related to various research professional associations. After examining the interconnections between different supply chain elements, the authors claimed that the most influencing components for university performance are research suppliers and education customers (Habib and Jungthirapanich, 2010b).

SEM seems to be a well-known tool in designing models for performance assessment. Ab Hamid (2014) operated with six factors constituting university behavior model such as leadership, university culture, productivity, stakeholders, employees, and performance (fig. 17). Having conducted questionnaires, the author employed SEM technique in order to reveal interrelationships between the characteristics. One of the results of SEM analysis was, for instance, the fact that university culture depends on leadership values, however, leadership is failed to have an effect on productivity values. Overall, it was stated that university performance tends to be affected by its stakeholders, as well as by its productivity factor (Ab Hamid, 2014).

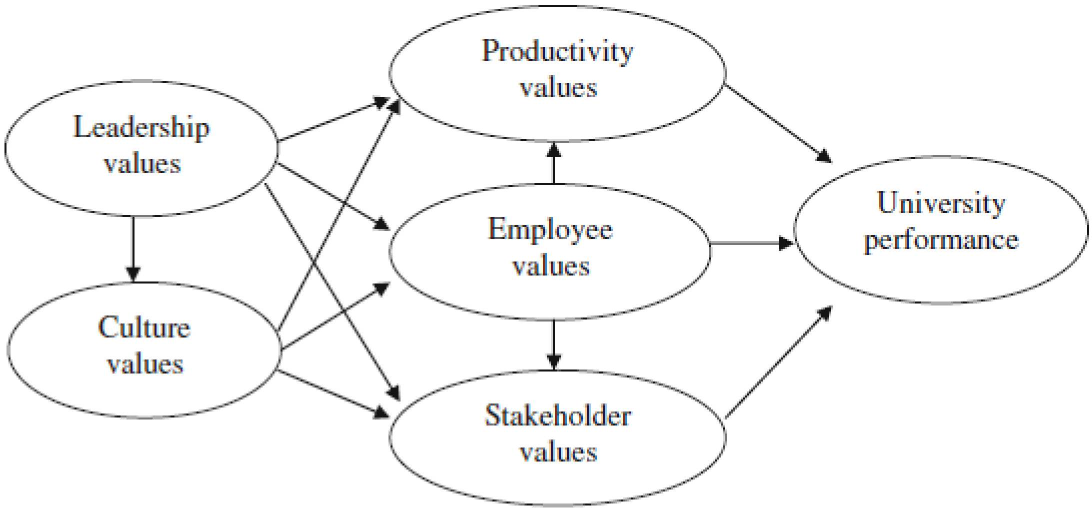


Figure 17. Value-based performance excellence model for higher education institutions (Ab Hamid, 2014)

Wang and Zhao (2009) approached the issue from a different perspective. The authors developed an entropy model in order to evaluate the order degree of university's organizational structure. Daily university's operations have been divided into six parts including "talent training, scientific research, human resource management, fund management, material management, and strategic management" (Wang and Zhao, 2009, 1). There are flows of labor, materials, information and cash running within an activity and between the activities. Figure 18 presents the model of operational tasks that consists of elements and contacts. The authors analyzed the order degree of the university system in terms of timeliness and veracity of the flows. By calculating the order degree level of the system, the model also helps university management to understand which departments should take actions in order to enhance timeliness of the system's order degree. For instance, according to the study's results, the higher order degree can be achieved by reducing several executive branches to simplify the system (Wang and Zhao, 2009).

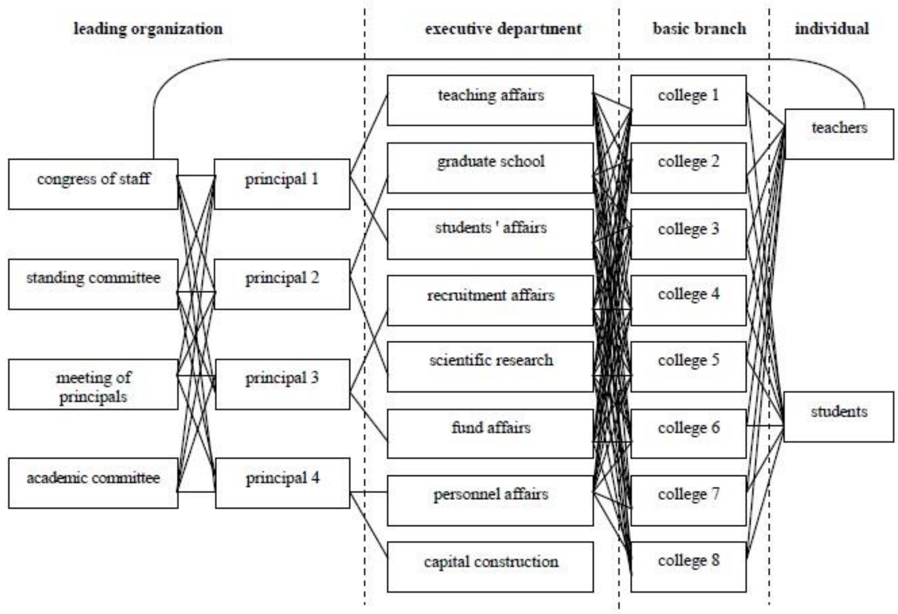


Figure 18. The model of university operational tasks (Wang and Zhao, 2009)

Mathematical modelling with dynamic characteristics adapted for the financial analysis of educational institution was studied by Kizatova (2016). The main purpose of the study is designing the model for budget allocation between university departments. The model takes into consideration the amount of students in each department in each year of study in a certain time period. In addition, there is a coefficient related to changes in student population through the years. By introducing the labor intensity of each department, the author suggested a formula for generating a payroll for an academic unit and for the growth rate of department's funds. The equation for a department's funds is presented in (7) and is composed of the formulas for the faculty's share in the study program D_{kaf}, the number of students *K* and the fixed amount of money *Norm* provided to the faculty as a basis. The variables depend on the university program *i*, the year of the study *j* of students in the program *i*, and the year of planning *t.* In addition, *p* represents the number of department. The share of the department p is calculated as in (8), where the share of the department D_{kaf} with the number p in the university program i for the students in the year of study *j* in the planning year *t*. There are the shares of the program's components or courses, and the parameter *D* means the share of the course k in the study program, the coefficient *Ind* reflects whether the department p teaches this course. The coefficient might be fractional as the department may partially teach the course (Kizatova, 2016).

$$Fot(p,t) = \sum_{i=1}^{N} \sum_{j=1}^{6} D_{kaf}(i,j,t,p) \times K(i,j,t) \times Norm(i,j,t) \tag{7}$$

$$D_{kaf}(i,j,t,p) = \sum_{k=1}^{N(i,j,t)} D(i,j,k,t) \times Ind(i,j,k,t,p) \tag{8}$$

Sonin, Khovanskaya and Yudkevich (2008) also focused on the finance structure of university and proposed a decision support model for hiring professors in the conditions of budget uncertainty. There are two types of lecturers in the proposed model: high quality and ordinary. The authors compared two different strategies: supporting top-quality professors and students, or focusing on ordinary lecturers and students. The following utility function U for the university was created (9):

$$U = s_H M_H \frac{Bm}{n_H+n_L} + s_L M_L \frac{Bm}{n_H+n_L} + \mu(M_H + M_L), \tag{9}$$

where M_H and M_L are, respectively, the quantities of talented and ordinary students in the university. The variables s_H and $s_L$mean quantitative measure of students' abilities for talented and ordinary students, respectively. B is the budget, *m* is the number of professors teaching one student during his or her time of study, n_H and n_L are the quantity of well qualified and ordinary professors in the university; and μ reflects the dependence of the university's grants from the government on the total number of students. Overall, the function has its maximum in two options presented in (10) and (11), where θ_n means the quantitative measure of a qualified professor's "usefulness". Overall, it can be concluded that in order to ensure the efficient university performance, the institution should either allocate its budget only on the top quality professors or hire only ordinary professors.

$$n_H = \frac{B}{\theta_n} \tag{10}$$

$$n_H = 0 \tag{11}$$

The model is supposed to help decision-makers to choose appropriate strategy and make a choice: either focusing on research activities and being small university with top-quality professors and students or being large institution mostly concentrating on teaching (Sonin, Khovanskaya and Yudkevich, 2008).

2.2.4 Models based on fuzzy logic and decision tree rules

Nurhudatiana and Anggraeni (2015) addressed research productivity in universities in their study. The authors explored the factors influencing the research productivity of three levels of academics: junior, intermediate, and senior ones. The aim is to forecast the number of publications by faculty members of different levels by generating decision tree models for each case. The data for the model were extracted from university's databases and contain the information about individual academic's publications in the past five years and their educational background. The example of the decision tree rules for junior faculty members is presented in the table 3. As a result of the simulation, it has been concluded that employees with PhD degree have the bigger potential to produce satisfying research output (Nurhudatiana and Anggraeni, 2015).

Table 3. The decision rules for junior faculty members (Nurhudatiana and Anggraeni, 2015)

№	Rule
1	IF degree level is less than PhD THEN he/she will not publish in the target year.
2	IF degree level is PhD AND publication intensity level in the field is high THEN he/she will publish in the target year.
3	IF degree level is PhD AND publication intensity level in the field is less than high AND prior publications >= 4

	THEN he/she will publish in the target year.
4	IF degree level is PhD AND publication intensity level in the field is less than high AND prior publications < 4 THEN he/she will not publish in the target year.

Another attempt to evaluate research productivity was made by Liu and Shi (2008). In their research, the authors applied fuzzy comprehensive evaluation (FCE) to assess university's research capability comprised of three aspects: research input, transformation and output capabilities. University's productivity was measured based on the several indexes categorized into these three aspects. The examples of indexes are "scientific research expense", "the amount of project", and "scientific research production" (Liu and Shi, 2008, 2). Since these characteristics are challenging to quantify, FCE appears to be an appropriate method to build an evaluation model. The authors calculated the power of each index by creating a comparison matrix. There are four evaluation degrees: bad, common, strong, and very strong. The university's research capability is a sum of evaluation degree quantified by experts and multiplied by the power. Overall, the proposed model is able to calculate the score related to the university's research productivity, thus, universities could be compared using one calculated indicator (Liu and Shi, 2008).

FCE method was also used by Song and Liu (2009) for the assessment of university competitiveness. The authors argued that the competitiveness of university is a fuzzy characteristic and cannot be evaluated precisely and numerically. Therefore, FCE approach was chosen for the assessment. As well as in the previous study (Liu and Shi, 2008), in Song and Liu's research (2009) three sets of variables were presented. The first set contains evaluation factors, the second one includes second-level indicators influencing those factors, and the third one called the comment set represents evaluation scores. Having created the fuzzy evaluation matrix, the author introduces the resulting value that defined the competitiveness of a university (Song and Liu, 2009).

Wu et al. (2010) utilized fuzzy analytic hierarchy process in their attempt to evaluate university's performance. The first level factors included into university evaluation system were divided into five categories involving "educational goals, customer satisfaction, develop strengths, running performance, school performance" (Wu et al., 2010, 1362). These indexes are also comprised of the second level factors. There were weights assigned to each sub-factor, and evaluation matrix was introduced. After calculating evaluation score, the appropriate level of performance have been assigned to the university in accordance with predetermined percentage system of grades (Wu et al., 2010).

Pal, Chakraborti and Biswas (2010) modelled a recruitment system for universities that supports staff allocation between the departments. The authors adapted Genetic Algorithm (GA) method to the penalty function in Fuzzy Goal Programming (FGP) in order to deal with multi-objective managerial problems. As a result, the model proposes an optimal number of employees in each department (Pal, Chakraborti and Biswas, 2010).

2.3 Summary of the review

The systematic literature review has shown that a little attention is paid to modelling of university management system in comparison with the vast amount of publications in the field of higher education (approximately 5%). However, among the articles that were derived through the systematic search there is a wide range of problems being solved by modelling approach. The table comprising all selected papers and their sources is presented in the appendix I.

Most of the proposed models have been designed as decision support systems that solve the problem of resource and staff allocation. On the one side, some of the articles propose generic view on university management, thereby, they provide a holistic insight into the issue. On the other side, several articles focus on particular aspects of higher education management such as recruitment or finances. Appendix II provides a table that describes the focuses of the reviewed articles, as well as the modelling methods utilized by their authors. In addition, the articles that include models for performance assessment were marked in order to extract the key factors influencing university's performance.

After the conduction of the literature review, it was decided to approach system dynamic method in order to answer the research questions. The reason of choosing SD method is explained by the fact that SD appears to be the most promising tool to study the processes that have place in such complex system as university.

2.4 Theoretical framework: System Dynamics

J.W. Forrester introduced System Dynamics in the middle of the 20^{th} century (Forrester, 1961). System Dynamics is described as a computer simulation method used to understand and manage the behavior of complex systems containing feedbacks (Moriya, 2012). Dynamic behavior of such systems is characterized by the fluctuation of the system parameters over time. SD approach allows including delays, feedbacks and non-linear patterns in developing a simulation model for industrial, social and any other complex system (Hallak et al., 2009). System Dynamics method has various practical applications such as analyses and forecast of the interrelated system characteristics, as well as decision-making and policy assessment through running and examining different scenarios (Moriya, 2012). In the given study, the SD is considered from the management point of view.

Every System Dynamics model consists of stocks and flows or levels and rates in the other terminology. Levels introduce accumulations changing over time. Rates are responsible for changes in the levels (Forrester, 1961). For instance, the balance on a financial account represents the level, incomes and expenses act for the rates.

Mathematical interpretation of the System Dynamics fundamental structure is as follows. The structure is defined by deferential or integral non-linear first degree equations in a form of (12):

$$\frac{d}{dt}x(t) = f(x,p), \tag{12}$$

where x represents a vector of levels, f means "a nonlinear vector-valued function", and coefficient p indicates a group of parameters. In the process of simulation, the computation takes place at discrete time intervals dt. The value of a variable in the moment t is calculated as a combination of its previous value at the time $(t\text{-}dt)$ and the net rate $x'(t)$ as it is illustrated in the equation (13) (Systemdynamics.org, 2017).

$$x(t) = x(t - dt) + dt \times x'(t - dt) \tag{13}$$

Feedback loops and delays comprise the basics of System Dynamics modelling. In the feedback loop, the flow of information eventually returns to its origin point with the new information that afterwards has an effect on processes in the loop. Another substantial aspect of the dynamic model appears to be delays in the system.

In order to create a SD model, the following steps must be performed (fig. 19). At the first step, the system under consideration is described and its behaviors are defined. The second stage of the process involves the conversion of the description into equations for levels and rates. At the third step, the simulation takes place. By developing alternative policies and structures, the determination of the most effective ones is performed at the fourth stage. Conclusions are drawn and discussions of the possible changes take place at the fifth step. Those changes are going to be implemented at the sixth step. After each step, there is a feedback to the previous steps to revise the model (Forrester, 1994).

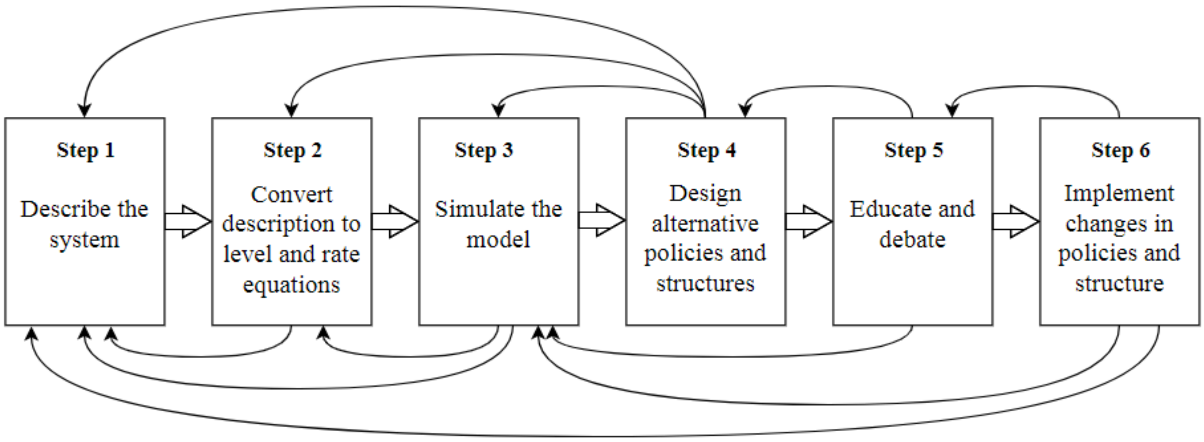


Figure 19. The steps in System Dynamic modelling (Forrester, 1994)

3 SIMPLE MODEL OF UNIVERSITY

In this chapter, the simple System Dynamics model of university is suggested. The main idea of the modelling is to show how the number of graduates and the number of university's research papers depend on certain factors controlled by university management. This research is focused on the relationship between the number of professors and the university outcome that is graduate students and scientific publications. The application of this model to the real data from the university is expected to facilitate decision-making process in the university in term of managing the number of academics in the institution. During the process of constructing the model, several ideas from the reviewed studies were used. The modelling is based on the theoretical framework introduced by J.W. Forrester that is presented in the figure 19 (Forrester, 1994). The following chapters are devoted to the stages illustrated in the picture.

3.1 Description of the university system

First, it is necessary to define the problem and the main goal of the modelling. As for the problem statement, it was mentioned previously that resource allocation seems to be a major concern in higher education (Rybnicek, 2015). The modelling of university system in this study aims at defining the university's outcome by means of managing the number of professors at the institution. In order to simplify the model, the university system is considered as a black box, where the relationship between input and output is the object under study. As in the previously mentioned studies (Habib and Jungthirapanich, 2009; Borooah, 1994), it was decided that university has two main products that are students and research. The general view of the model is illustrated on the figure 20 where L is the number of academics of different levels in a university, K – capital spend on teaching and research activities, such as academics' salary or acquisition of equipment, S – the number of graduate students, and R – the number of publications.

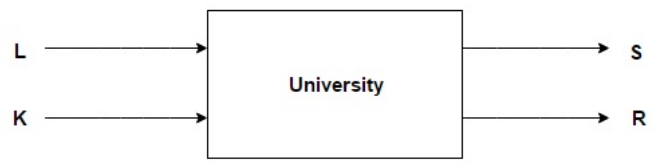


Figure 20. University as “a black box”

Secondly, the elements of the system and their connections with each other should be indicated and feedback loops is to be derived. Thus, the results was the developed causal loop diagram presented on the figure 21.

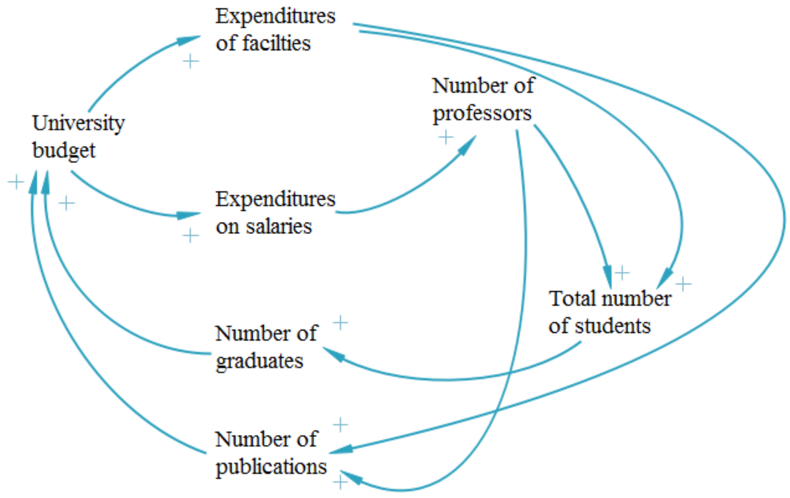


Figure 21. Causal loop diagram of university model

As can be seen from the causal loop diagram, there are several positive loops. The first loop is “University budget – Expenditures on facilities – Total number of students – Number of graduates – University budget”. An increase in the budget allows a university to purchase new equipment, such as computers, or rent more space for educational purposes. Thus, the university will be able to accept more students, and total number of students will be raised. Therefore, the number of graduates will also grow. We assume that the university income consists of payments for graduate students and payments for research papers. As it can be concluded, number of graduates directly influences the university budget. The second positive loop is “University budget – Expenditures on salaries – Number of professors – Number of publications – University budget”. An increase in the budget allows hiring more academics, thus, the number of publications is expected to grow and, therefore, it guarantees the increase in university budget. Finally, the third and the fourth loops describe the positive correlation between expenditures on facilities and the number of publications and the correlation between expenditures on salaries and the number of graduate students, respectively.

3.2 Level and rate equations

In the following stage, the transition to the level and rate equations occurs. The stock and flow diagram was built based on causal loop diagram (appendix III). The diagram was created in Vensim simulation software and it forms a model. However, the parameter representing the total number of students were excluded from the model. By conducting the linear regression analysis based on the data from Lappeenranta University of technology, it was concluded that the amount of graduates does not depend directly on the total number. Thence, the quantity of graduates in a certain year might be affected by the amount of professors and university’s finances in that year.

Table 4 shows the values of the two investigated parameters: total number of students and number of graduates with the three-year delay. The regression analysis was conducted using Microsoft Excel. This analysis is used to find a connection between two or more indexes. It provides an equation that connects those indexes. Then the regression statistics (table 5) were examined. The R-square parameter defines whether the model reflects the real system or not. The values for R-square range from 0 to 1, and the parameter must be greater than 0.5. In this particular analysis it is equal to 0,000065, that is very low, proving that there is no vivid dependency between total number of students and graduates. This might be explained by vague time of the study of Finnish students, they do not have clear deadlines for graduation. As it can be seen, the modelling process did not flow linearly, it was exposed to several changes forcing to return back to the previous steps and revise the model.

Table 4. Values for the number of students and the number of graduates with the three-year delay

Total number of Master's degree students	Number of Master's degree graduates
3897	433
4257	470
4568	492
5018	517
5251	638
4502	770
3998	609
3617	872
2801	573
2798	588
1825	615
1925	584
1966	596
1955	575

Table 5. Regression statistics

Regression statistics	
Multiple R	0,008082
R Square	6,53E-05
Adjusted R Square	-0,09084
Standard Error	113,2551
Observations	13

The model consists of three levels, six rates, two auxiliary variables and three constant variables. Three levels in the model are the following:

- "Graduates" showing the amount of graduate students on a master's programs at the university in the current year;
- University budget displaying the university's finances in the beginning of the year;
- Research papers presenting the amount of publications produced by the university.

The rates include changes in the number of graduate students, income and expenditures of the university, research input and output. Auxiliary variables consist of separated expenditures on facilities and salaries. The parameter “Expenditures on salaries” is calculated as a presumed average professor’s salary (3500 euro) multiplied by the number of professors. “Number of professors”, “Payment per graduated student” and “Payment per research paper”, received from the government, comprise constant parameters. All the variables and the equations used in the model are presented in the table 6.

Table 6. Parameters used in the model

Variable	Type	Equation
Graduates	Level	Graduates + Graduates in-Graduates out
Graduates in	Rate	A*(Expenditures on facilities^a)*("Number of professors"^b)
Graduates out	Rate	DELAY1(Graduates*1 , 2)
University budget	Level	University budget on facilities and salaries + Income - Ammortisation
Income	Rate	Graduates*Payment per graduated student + Research papers*Payment per research paper
Amortisation	Rate	Expenditures on facilities + Expenditures on salaries
Expenditures on facilities	Auxiliary	University budget on facilities and salaries - Expenditures on salaries
Expenditures on salaries	Auxiliary	Number of professors*3500
Payment per graduated student	Constant	-
Payment per research paper	Constant	-
Research papers	Level	Research papers+Papers in-Papers out
Papers in	Rate	A*(Expenditures on facilities^a)*("Number of PhD, professors"^b)

Papers out	Rate	DELAY1(Research papers*1 , 2)
Number of PhD, professors	Constant	-

There is a control parameter that is chosen to be customized in order to define the most suitable university strategy. This strategy must meet the university needs such as the appropriate number of graduates and research papers per year. The control parameter is the number of professors. It is the constant parameter and must be changed manually. The model includes several delays such as average time of study and average time of making research. Since only master's degree students are considered, it have been decided to set the time taken to accomplish a degree program for the rate "Graduates out" as 2 years. The average time for producing an academic paper ("Papers out") was set to be also 2 years. The coefficients used in the equations for the number of graduate students ("Graduates in") and the number of research papers ("Papers in"), such as a, b, A, are supposed to be defined by the regression analysis applied to the university data.

Modelling for such parameters as "Paper in", "Research papers", and "Papers out" were taken from Galbraith (2010, 120). In addition, the same way of modelling were applied to the following elements: "Graduates in", "Graduates", "Graduates out".

3.3 Simulation and the results

Simulation of the proposed model was done by using Vensim simulation software. The data for the model were taken from the statistics of Lappeenranta University of Technology. In addition, several assumptions were made to run the model.

3.3.1 Defining the values for the parameters

In order to verify the model, the data from Lappeenranta University of Technology have been requested. Unfortunately, some of the data were challenging to obtain, for instance, financial data. A table containing all the received information is presented in the appendix IV. Inconsistency of the data can be explained by the fact that in the beginning of 2010 the calculation system of the funding formula, classifications of both academic staff and academic publications, as well as the standards for the reporting system of the university have been changed significantly.

Thereby, in this study, there is no possibility of using the real data from the LUT to prove the model. However, some values for the variables have been founded in the LUT statistics from the website of the university (Lut.fi, 2017) and, in addition, some of the values were extracted from the provided list of values. The variables and their values required for the run of the model is given in the table 7.

The coefficients in the linear and non-linear regression equations were taken intuitively. The purpose was to show a steady increase in the number of research papers and graduates depending on the growth in the number of professors and university budget on facilities. The equations with the chosen coefficients are illustrated below. The equation (14) depicts the formula for the quantity of research papers, and the equation (15) shows the calculation of the number of graduate students. The function graphs are presented in the figures 22 and 23.

$$5*(\text{Expenditures on facilities}\verb|^|0.002)*(\text{"Number of PhD, professors"}\verb|^|0.3) \tag{14}$$

$$0.05*(\text{Expenditures on facilities}\verb|^|0.2)*(\text{"Number of PhD, professors"}\verb|^|0.3) \tag{15}$$

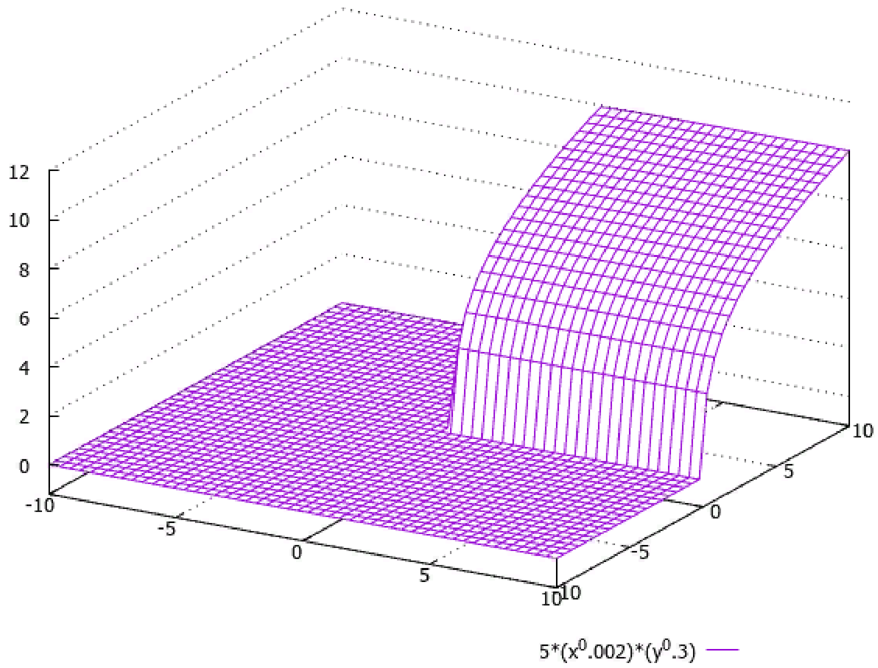


Figure 22. The function graph for the number of research papers

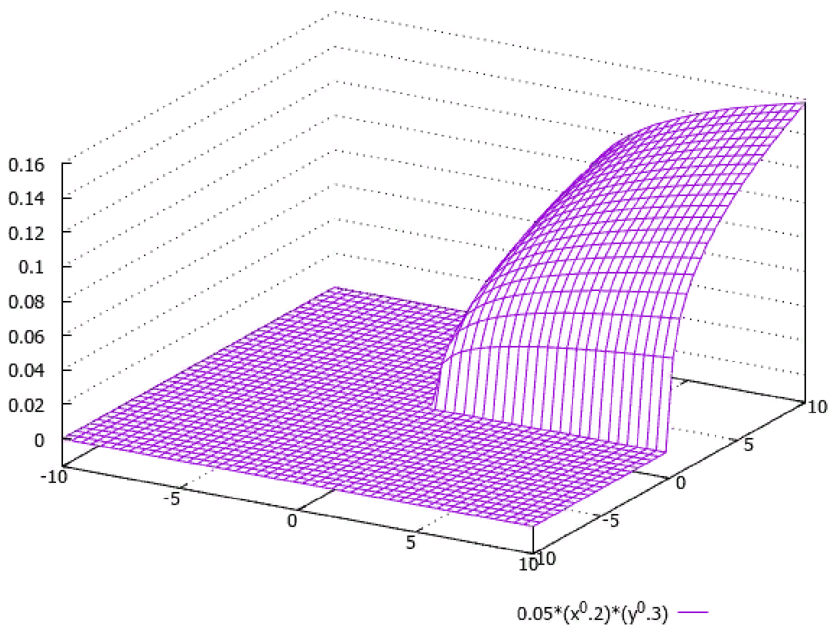


Figure 23. The function graph for the number of graduate students

The following assumptions were taken:

- The university receives a payment for each graduated student that is equal to 500 euros.
- In addition, there is a payment for each peer-reviewed research paper equal to 50 euros.
- The university budget mentioned at LUT's key facts is 46 000 000, however, since only master's degree students are considered in this study, it was decided to take 20 000 000 as the university's finances spent on facilities and professors for the students.
- The values for initial numbers of graduates and scientific publications were derived from the data provided by LUT.

Table 7. The variables and their values

Variable	Initial value
Graduates	872
Graduates in	0.05*(Expenditures on facilities^0.2) *("Number of PhD, professors"^0.3)
Graduates out	DELAY1(Graduates*1 , 2)
University budget	20000000
Income	-
Amortisation	-
Expenditures on facilities	-
Expenditures on salaries	-
Payment per graduated student	500
Payment per research paper	50
Research papers	555
Papers in	5*(Expenditures on facilities^0.002)*("Number of PhD, professors"^0.3)
Papers out	DELAY1(Research papers*1 , 2)
Number of PhD, professors	125

3.3.2 Running the model

The simulation were undertaken with the help of Vensim software. The initial time of the simulation were stated as 2010 and the final time is 2017. The time step is 1 year (fig. 24). Before running the simulation, the syntax of the model has been checked. The simulation has been done successfully, and the results were presented as graphs.

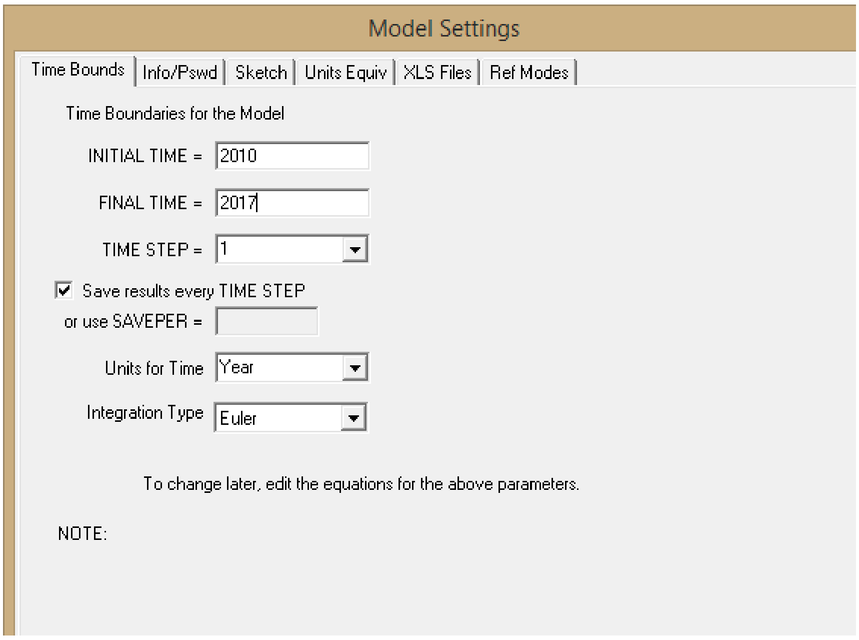


Figure 24. Model settings

3.3.3 Obtaining the results, designing and comparing the alternative policies

After running the model, the following graphs for the two parameters under study have been received (fig. 25, 26, 27). As it can be seen, the model is customized in a way that ensures a steady growth in the number of papers and graduates.

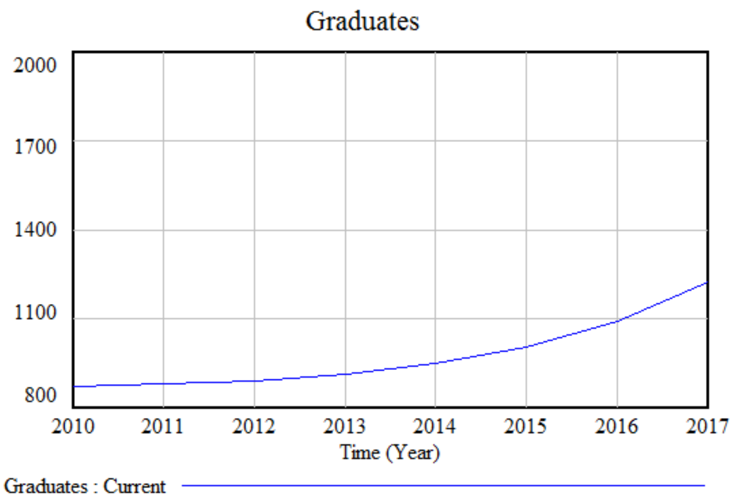


Figure 25. The growth in the number of graduate students between 2010 and 2017 (125 professors)

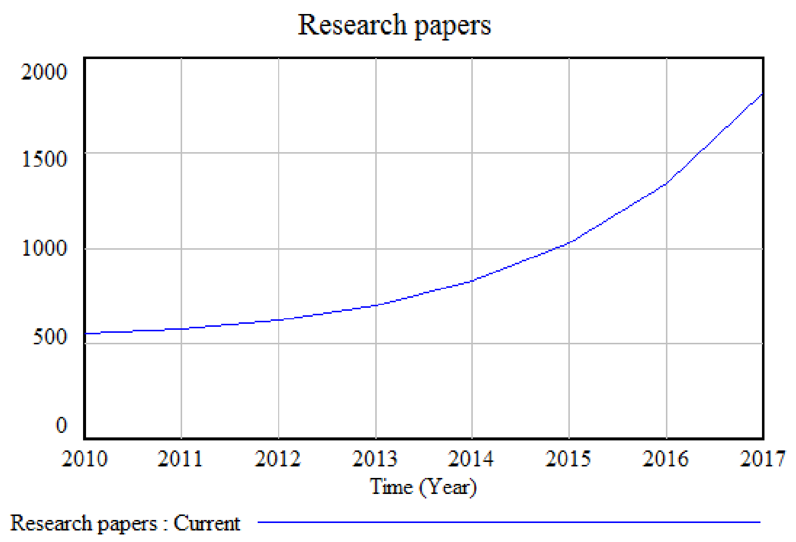


Figure 26. The growth in the number of research papers between 2010 and 2017 (125 professors)

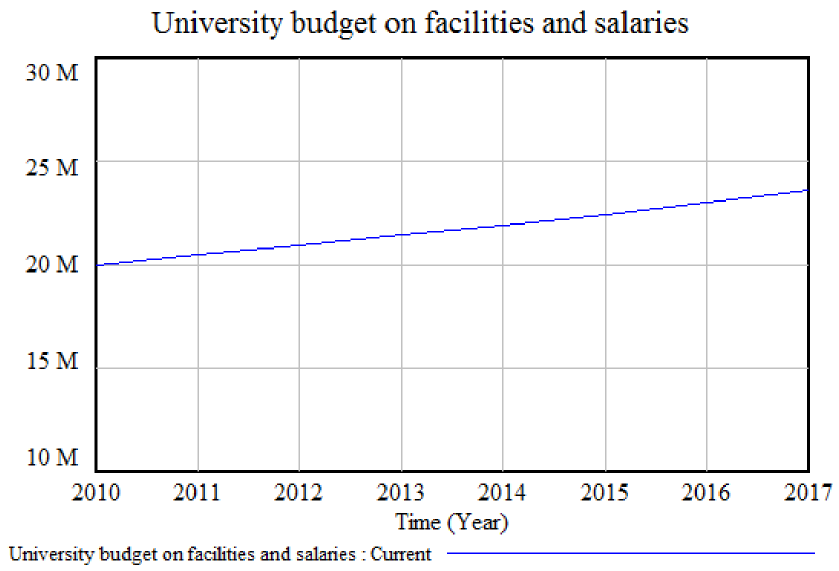


Figure 27. The growth in the university budget between 2010 and 2017 (125 professors)

As the main idea of the study is to find a way to predict university's outcomes by varying the number of academics, the value of the control parameter "Number of professors" was changed from 125 to 555. The graphics below show the changes in the predictions (fig. 28, 29). As it can be seen, the quantities of graduates and research papers are expected to increase by about 200 students and 800 papers to the year 2017.

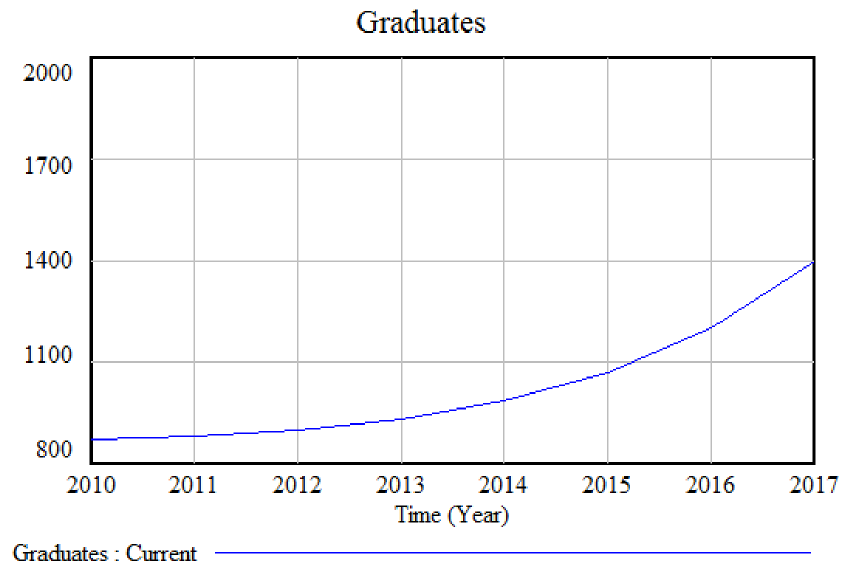


Figure 28. The growth in the number of graduate students between 2010 and 2017 (555 professors)

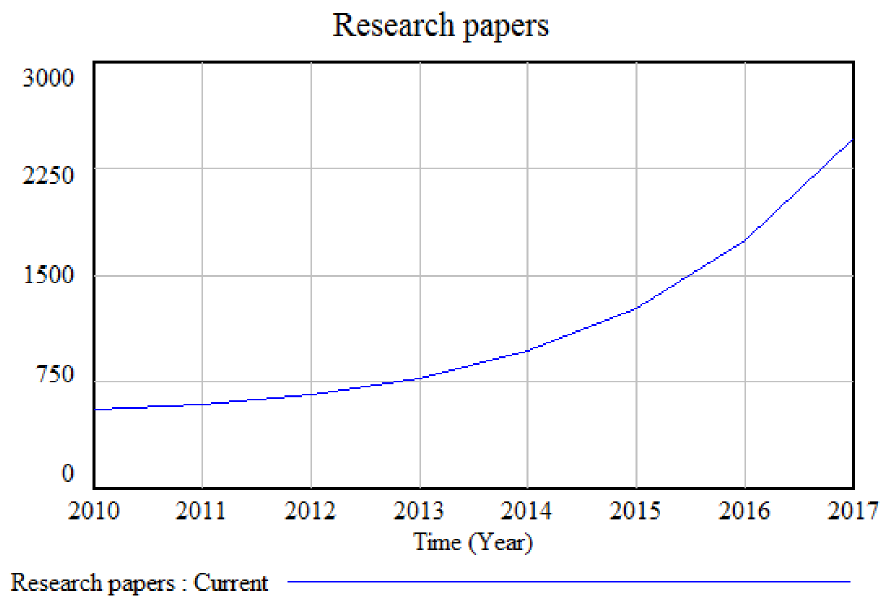


Figure 29. The growth in the number of research papers between 2010 and 2017 (555 professors)

Thus, two different scenarios were provided. The number of professors was 125 and 555 in the first and second case, respectively. The model has proved the increase in the university's outcome by leveraging its labor. However, the more consistent data is required to perform thorough analysis of the results with accurate numbers. Since the idea of the modelling in the study was to show the possibility of modelling university system for the specific case, the conclusion can be drawn that is as follows. The problem statement was managing the quantity of academics, and it was proven that System Dynamic modeling could successfully deal with such cases and facilitate decision-making processes on this issue.

4 DISCUSSIONS

This chapter presents the implications of the research and propose the suggestions for the future study. In addition, there is a comparison of the chosen theoretical framework and the practical realization of the framework. The chapter aims to provide the answer to the stated research questions and explain the process of research. The purpose of the modelling was to provide a general insight on the issue of resource allocation in term of number of employees. The problem stated at the beginning of the research was to find a way to model university system in order to predict the results of certain managerial decision.

First, the significant amount of the previous studies was considered to investigate different problems and their solutions that already have been addressed. The quantity of publications devoted to the modelling in higher education sector appeared to be very small in comparison with the vast amount of publications about university management. That fact might be explained by the complex structure of the university system. However, despite that, the authors of the reviewed studies have attempted to address that complicated issue and proposed their models that describe either the whole university system at general level or a part of that system. The majority of the papers under the review address either resource allocation or performance assessment of a university. As for the resource allocation, some of the papers are devoted to staff allocation between the departments, the other ones – to the distribution of finances and equipment. Performance assessment in the papers occurs in a form of the evaluation of the quality of research papers, teaching, or university's performance in general. The various approaches to the modelling were discovered through the literature review, but the most effective seemed to be System Dynamics modelling which has been chosen as the theoretical framework for the given research. The main reason of selecting SD approach was its adaptability to complex and dynamic university system, as well as its ability to predict the future conditions.

Thereby, the research objective was stated as to create a predictive model for the main university's products, in that case, both students and research papers. In addition, the goal was to investigate how the quantity of the academics influence the outcomes. After the creation of the model from the general point of view, some data were extracted from the ones provided by LUT. In addition, the other data were imitated to fill all required fields in the model. Thereby, the two possible scenarios were simulated that include the change in the number of academics to predict the variations in the university outcomes such as the quantity of graduate Master's degree students and the number of scientific publications. The simulation ran successfully and the results were adequate that allows us to believe that the proposed model is able to facilitate managerial decisions in terms of staff hiring. The SD model revealed the dynamic changes in the number of graduates and scientific publications taking into account the delays.

The process of modelling passed through the steps mentioned in Forrester (1994) with the exclusion of the last stage which is the implementation of the most acceptable policies to the model. This stage will be completed when the required data from the real university system is fully available. It will allow comparing the alternative values for the number of academics to indicate the most promising for the implementation. However, the provided model can potentially help university decision-makers to understand how the composition of teaching staff influences the university performance and they have an opportunity to run the simulation using their own data.

As, unfortunately, the data were inconsistent and the information reflected a short time period, it was challenging to conduct regression analysis and, hence, to derive accurate equations for the relationship between the following parameters under study: "Graduates in", "Papers in". There was an attempt to presume possible values of the coefficients in the equations in order to check the efficiency of the model. The model is expected to be more coherent when the complete data for at least 15 years are applied. Thus, there is a large room for an improvement. For the future studies it would be useful to divide all the teaching staff in the model into categories in respect with their academic level such as professors, assistant professors, and PhD students who is also lecturing at the university. By varying number in these separated categories, university management is allowed to enhance recruitment process at the institution and hire needed and potentially effective employees.

5 CONCLUSIONS

Complex university system and underlying relationships between different elements such as students, professors and finances are responsible for challenges in the process of policy making in university. System Dynamics serves as an effective method to solve this problem. The current study aimed to find a way to manage the number of academics in a university in order to have sufficient number of graduate students and scientific publications.

Therefore, the stated research questions were as follows.

RQ1: What is the most efficient framework to develop predictive model in terms of studying the dependence between professors, students, and research in a university?

RQ2: How the number of academics in a university influences the number of graduates and research papers produced by this institution?

To answer the research questions, the theoretical investigation of the current solutions was conducted, as well as the simple university model was developed in order to investigate the relationships between the above-mentioned factors. Two scenarios of the system behavior were simulated to reveal the consequences of the changes in the number of professors.

First of all, conducting the systematic literature review of the most relevant research papers, the most suitable theoretical framework for the study has been chosen. The publications involved various modelling methods; however, System Dynamics appeared to be the most promising since it is able to effectively handle sophisticated social systems containing numerous components and interrelations. Secondly, the general university model has been suggested to use in university's decision-making. The modelling process was performed in accordance with the steps suggested in the theoretical framework. After deriving some ideas from the previous studies and observing the current situation in the universities in Finland, the causal loop diagram has been developed showing the components and their relationships that were the centers of interest in this research. The data needed to create the equations for the model and for the simulation were requested from

Lappeenranta University of Technology. Unfortunately, it was challenging to obtain all essential data, especially, the financial one. Thus, the part of the data was imitated in order to run the simulation and show the approximate results. Nevertheless, the actual data allowed executing regression analysis to reveal the absence of actual dependence between certain elements in the system. As a result, the predictive model for the university has been created. The results of the simulation illustrated the increase in the number of graduate students and research papers influenced by the increase in the number of professors. The first and the second cases include 125 and 555 academics, respectively. The change in the number of academics has caused the growth in the amount of graduates by 200, and the quantity of scientific publications have increased by 800.

Overall, although the simulation was imitative, the proposed model could help university management to forecast and compare the effects of changes in the quantity of the teaching staff and, hence, manage university's human resources. By applying their own data, the managers are able to customize the model to fit the conditions of their university system. There are various opportunities for the future researches on that issue and for the expansion of the model to the next levels of approximation. For example, it would be useful to divide the teaching staff to professors, associate professors and so on, in order to investigate the most efficient ratio between those categories.

6 SUMMARY

The main goal of the study is to propose a predictive model of university allowing university's decision-makers to trace the effects of their strategies. In the given research the dependence between the numbers of professors in higher education institution and its products, such as graduate students and scientific publications, is investigated. Since university appears to be a complex non-linear system, the system thinking approach seems to be the most appropriate management strategy. In particular, by utilizing System Dynamics, university management is able to predict the more precise results of its decisions.

First of all, the literature review was performed to determine the most appropriate theoretical framework that will facilitate the modelling. Several types of modelling approaches were discovered through the review including System Dynamics, qualitative methods, and various static mathematical models. System Dynamics approach has been chosen as the framework and the stages of the modelling process were discovered. Secondly, as the first step, the university system was described, and its components and interrelationships were defined. Subsequently, the stock and flow diagram was developed based on causal loop diagram. The next steps of the modelling involved creating the equations for the components of the system and applying the data that were both obtained and imitated. Two scenarios were simulated to show the consequences of the changes in the number of academics. As a result, the model was able to forecast the increase in the numbers of university outcomes caused by the growth in the number of professors.

Although the data were partly imitated, the model can potentially facilitate decision-making process in university management. By applying their own data, the management is able to customize the model and adjust it to their university's structure. There is a lot of potential to expand the model and continue the research. For instance, all teaching staff could be separated to professors, associate professors and so on, in order to investigate the most efficient ratio between those categories.

REFERENCES

Ab Hamid, M. (2014). Value-based performance excellence model for higher education institutions. *Quality & Quantity*, 49(5), pp.1919-1944.

Adham, K., Kasimin, H., Mat Isa, R., Othman, F. and Ahmad, F. (2015). Developing a Framework for a Viable Research University. *Systemic Practice and Action Research*, 28(5), pp.503-525.

Barlas, Y. and Diker, V. (2000). A Dynamic Simulation Game (UNIGAME) for Strategic University Management. *Simulation & Gaming*, 31(3), pp.331-358.

Bing, L., Yuan, S. and Yuan, L. (2009). Research on Customer Relationship Management Intelligent Decision-Making Mechanism of University Based on System Dynamics. In*: 2009 International Workshop on Intelligent Systems and Applications.*

Boronico, J., Murdy, J. and Kong, X. (2014). Faculty Sufficiency And AACSB Accreditation Compliance Within A Global University: A Mathematical Modeling Approach. *American Journal of Business Education*, 7(3), pp.213-218.

Borooah, V. (1994). Modelling institutional behaviour: A microeconomic analysis of university management. *Public Choice*, 81(1-2), pp.101-124.

Casper, C. and Henry, M. (2001). Developing Performance-Oriented Models for University Resource Allocation. *Research in Higher Education*, 42(3), pp.353-376.

Dahlan, S. and Yahaya, N. (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. and Sinha, D. (2016). Strategic management of technical university: structural equation modelling approach. *Journal of Modelling in Management*, 11(1), pp.75-90.

Forrester, J. (1961). Industrial dynamics. Cambridge, MA: The M.I.T. Press.

Forrester, J. (1994). System dynamics, systems thinking, and soft OR. *System Dynamics Review*, 10(2), pp.245-256.

Galbraith, P. (1999). Systems thinking: a missing component in higher educational planning?. *Higher Education Policy*, 12(2), pp.141-157.

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

Habib, M. and Jungthirapanich, C. (2009). Research Framework of Educational Supply Chain Management for the Universities. In: *2009 International Conference on Management and Service Science.*

Habib, M. and Jungthirapnaich, C. (2010a). An empirical research of integrated educational management for the universities. In: *2010 2nd IEEE International Conference on Information Management and Engineering.*

Habib, M. and Jungthirapanich, C. (2010b). An empirical research of educational supply chain for the universities. In: *2010 IEEE International Conference on Management of Innovation & Technology*. pp.186-191.

Hallak, L., Pakštas, A., Oriogun, P. and Novakovic, D. (2009). Decision Support Systems for University Management Processes: An Approach towards Dynamic Simulation Model. In: *Second International Conference on Computer and Electrical Engineering*. IEEE Computer Society, pp.556 - 559.

Hawari, N. and Tahar, R. (2015). A dynamic model of balanced scorecard to enhance strategic university planning process. In: *2015 International Symposium on Mathematical Sciences and Computing Research (iSMSC).* pp.361-366.

Kennedy, M. (2000). Towards a Taxonomy of System Dynamics Models of Higher Education. In: *18th International Conference of the System Dynamics Society*.

Kitchenham, B. (2004). Procedures for performing systematic reviews. Keele, UK, *Keele University*, 33(2004), pp.1-26.

Kizatova, N. (2016). A dynamic model of generating the payroll of the academic teaching staff in higher educational institutions. *Modern Economics: problems and solutions*, 79(7), pp.15-27. (In Russian).

Liu, W. and Shi, C. (2008). Evaluation for University Scientific Research Capability Based on FCE. In: *4th International Conference on Wireless Communications*, Networking and Mobile Computing. pp.1-4.

Lut.fi. (2017). *Key Facts - LUT*. [online] Available at: https://www.lut.fi/web/en/get-to-know-us/introducing-the-university/key-facts [Accessed 23 Nov. 2017].

Matsuo, T. and Fujimoto, T. (2008). A University Management Analysis System for Qualitative Strategy Planning. In: *19th International Conference on Systems Engineering*. pp.177-182.

MEPS VSU. (2017). Современная экономика: проблемы и решения. [online] Available at: https://meps.econ.vsu.ru/index.php/meps [Accessed 18 Apr. 2017].

Moriya, K. (2012). System Dynamics. In: *Field Informatics*. Berlin, Heidelberg: Springer.

Nurhudatiana, A. and Anggraeni, A. (2015). Decision tree modeling for predicting research productivity of university faculty members. In: *2015 International Conference on Data and Software Engineering*. pp.70-75.

Pal, B., Chakraborti, D. and Biswas, P. (2010). A genetic algorithm method to fuzzy goal programming formulation based on penalty function for academic personnel management in university system. In: *2010 Second International conference on Computing, Communication and Networking Technologies.*

Publications of HSE. (2017). Publications of HSE. [online] Available at: https://publications.hse.ru/en/ [Accessed 18 Apr. 2017].

Robledo, L., Sepulveda, J. and Archer, S. (2013). Hybrid simulation decision support system for university management. In: *the 2013 Winter Simulation Conference*. pp.2066-2075.

Rodrigues, L., Hebbar, S., Suraj, S. and Leekha, D. (2012). Modelling and Simulation of Quality Management in Higher Education: A System Dynamics Approach. In: *2012 Fourth International Conference on Computational Intelligence, Modelling and Simulation.* pp.304-309.

Rybnicek, R. (2015). Challenges for a modern university management. In: *9th International Scientific Conference "Economic and Social Development".* Varazdin: Varazdin Development and Entrepreneurship Agency, p.78.

Sababi Pour Asl, G. and Bafandeh Zendeh, A. (2014). Strategic plan compilation using system dynamics modeling: case study of a university. Education, *Business and Society: Contemporary Middle Eastern Issues*, 7(4), pp.277-292.

Song, Y. and Liu, F. (2009). Fuzzy Comprehensive Evaluation Model of Core Competitiveness of Universities Based on Information Fusion. In: *2009 Asia-Pacific Conference on Information Processing*. pp.35-37.

Sonin, K., Khovanskaya, I. and Yudkevich, M. (2008). Postroenie issledovatelskogo universiteta: struktura finansirovaniya i usloviya najma professorov. *Voprosy ehkonomiki*, 12. (In Russian).

Systemdynamics.org. (2017). *What is System Dynamics << System Dynamics Society*. [online] Available at: http://www.systemdynamics.org/what-is-s/ [Accessed 27 Aug. 2017].

Wang, X. and Zhao, G. (2009). Application of entropy model to evaluate order degree of university management structure. In: *2009 International Conference on Computational Intelligence and Software Engineering*.

Wu, C., Lv, L., Qi, W. and Zhang, Y. (2010). Research on an empirical research program of university organizational performance assessment. In: *2010 International Conference on Machine Learning and Cybernetics*. pp.1362-1367.

APPENDIX I

Articles used in the literature review.

Name	Author	Year	Source
Research Framework of Educational Supply Chain Management for the Universities	Md. Mamun Habib	2009	IEEE Xplore Digital Library
An empirical research of integrated educational management for the universities	Md. Mamun Habib	2010	IEEE Xplore Digital Library
An Empirical Research of Educational Supply Chain for the Universities	Md. Mamun Habib Chamnong Jungthirapanich	2010	IEEE Xplore Digital Library
Research on an empirical research program of university organizational performance assessment	Chang-Li Wu Ling Lu Wei Qi Yu Zhang	2010	IEEE Xplore Digital Library
A Genetic Algorithm Method to Fuzzy Goal Programming Formulation Based on Penalty Function for Academic Personnel Management in University System	Bijay Baran Pal Debjani Chakraborti Papun Biswas	2010	IEEE Xplore Digital Library
Hybrid simulation decision support system for university management	Luis F. Robledo Jose Sepulveda Sandra Archer	2013	IEEE Xplore Digital Library
Relationship Management Intelligent Decision-making Mechanism of University Based on System Dynamics	LIU Bing SU Yuan LI Yuan	2009	IEEE Xplore Digital Library
Fuzzy Comprehensive Evaluation Model of Core Competitiveness of Universities Based on Information Fusion	Yunfeng Song Fuming Liu	2009	IEEE Xplore Digital Library
A University Management Analysis System for Qualitative Strategy Planning	Tokuro Matsuo Takayuki Fujimoto	2008	IEEE Xplore Digital Library

(continues)

APPENDIX I (continues)

Application of entropy model to evaluate order degree of university management structure	Wang Xiaoping Zhao Guogang	2009	IEEE Xplore Digital Library
Evaluation for University Scientific Research Capability based on FCE	Weiwei Liu Chunsheng Shi	2008	IEEE Xplore Digital Library
A dynamic model of balanced scorecard to enhance strategic university planning process	Nurul Nazihah Hawari Razman Mat Tahar	2015	IEEE Xplore Digital Library
Strategic management of technical university: structural equation modelling approach	Dandagi, Shivaprasad Bhushi, Umesh Bagodi, Virupaxi Sinha Deepankar	2016	ProQuest ABI/INFORM Collection
Developing a Framework for a Viable Research University	Adham Khairul Akmaliah Kasimin Hasmiah Mat Isa Rosmah Othman Fatimah Ahmad Faizah	2015	ProQuest ABI/INFORM Collection
Faculty Sufficiency And AACSB Accreditation Compliance Within A Global University: A Mathematical Modeling Approach	Boronico, Jess Murdy, Jim Kong, Xinlu	2014	ProQuest ABI/INFORM Collection
Strategic plan compilation using system dynamics modeling: case study of a university	Sababi Pour Asl Golnaz; Bafandeh Zendeh Alireza	2014	ProQuest ABI/INFORM Collection
Value-based performance excellence model for higher education institutions	Ab Hamid, Mohd Rashid; Bin	2015	ProQuest ABI/INFORM Collection
System dynamics: A lens and scalpel for organisational decision making	Galbraith Peter	2010	ProQuest ABI/INFORM Collection
Decision Tree Modeling for Predicting Research Productivity of University Faculty Members	Arfika Nurhudatiana Adilla Anggraeni	2015	Scopus
Developing performance-oriented models for university resource allocation	Cheryl A. Casper Myron S. Henry	2001	Scopus

(continues)

APPENDIX I (continues)

Modelling and Simulation of Quality Management in Higher Education: A System Dynamics Approach	Lewlyn Lester Raj Rodrigues, Sunith Hebbar, Sinchana Suraj Divya Leekha	2012	IEEE Xplore Digital Library
A dynamic simulation game for strategic university management (UNIGAME)	Yaman Barlas Vedat Güçlü Diker	2000	Other source (LUT Finna)
Modelling institutional behaviour: A microeconomic analysis of university management	Vani K. Borooah	1993	ProQuest ABI/INFORM Collection
A System Dynamics Model for Determining Educational Capacity of Higher Education Institutions	S. F. Mohd Dahlan N. A. Yahaya	2010	IEEE Xplore Digital Library
A dynamic model of generating the payroll of the academic teaching staff in higher educational institutions	Kizatova Nadezhda	2016	(MEPS VSU, 2017)
[Formation of research university: financial structure and terms of employment.] Postroenie issledovatelskogo universiteta: struktura finansirovaniya i usloviya najma professorov	Sonin, K. Khovanskaya, I. Yudkevich, M.	2008	(Publications of HSE, 2017).

APPENDIX II

The summary table of the literature review.

Document title	Framework	Problems and solutions	Focus of the research	Assessment of university's management
A dynamic model of balanced scorecard to enhance strategic university planning process (Hawari and Tahar, 2015)	System Dynamics and Balance Scorecard	Design and simulation of a dynamic system with the help of the balanced scorecard framework in order to support decision-making and planning processes in universities.	University strategies and policies and their implications	Yes. Study how different policies affect university's performance.
A System Dynamics Model for Determining Educational Capacity of Higher Education Institutions (Dahlan and Yahaya, 2010)	System Dynamics	A SD model enabling effective resource allocation in universities is developed in order to meet supply and demand issues of an academic program.	Educational capacity Resource allocation.	No.
Hybrid simulation decision support system for university management (Robledo, Sepulveda and Archer, 2013)	System Dynamics Agent-based modelling	A hybrid model was designed to support decision-making process in university in terms of resource management. The model is able to predict enrollment and retention rates for the next year at both university and department levels.	Resource allocation Enrollment rate Retention rate	No.

(continues)

APPENDIX II (continues)

Modelling and Simulation of Quality Management in Higher Education: A System Dynamics Approach (Rodrigues et al., 2012)	System Dynamics	A model for assessing the quality of university services affected by various factors.	Quality management	Yes. The factors that determine university's quality management are elicited. The TQM index is used for the assessment.
Research on Customer Relationship Management Intelligent Decision-Making Mechanism of University Based on System Dynamics (Bing, Yuan and Yuan, 2009)	System Dynamics	A model defining the best portfolio programme to enhance customer satisfaction.	CRM Customer satisfaction	No.
Strategic management of Technical university: structural equation modelling approach (Dandagi et al., 2016)	Structural equation modelling System Dynamics	A model for strategic management for technical university was built with the help of structural equation modelling. The model is supposed to evaluate university's adaptability to ever-changing environment.	Adaptability of university	No.

(continues)

APPENDIX II (continues)

Strategic plan compilation using system dynamics modeling: case study of a university (Sababi Pour Asl and Bafandeh Zendeh, 2014)	System dynamics	A model to predict the number of BA, MA and PhD students in the future. The model can be used for university strategic planning.	Student demand	No.
System dynamics: A lens and scalpel for organizational decision making (Galbraith, 2010)	System Dynamics	The author proposed a general dynamic model of university's structure to show the application of SD in this domain.	University's strategy	No.
A Dynamic Simulation Game (UNIGAME) for Strategic University Management (Barlas and Diker, 2000)	System Dynamics	An interactive game based on SD modelling is used to trace the implications of different strategies.	Quality of teaching and research Student ratio	No.
A University Management Analysis System for Qualitative Strategy Planning (Matsuo and Fujimoto, 2008)	Qualitative simulation	Decision support model for qualitative assessment of university's operations.	University's operations	Yes. It is supposed to analyze effective operations.
Decision Tree Modeling for Predicting Research Productivity of University Faculty Members (Nurhudatiana and Anggraeni, 2015)	Decision Tree modelling	Decision tree model to predict research productivity of junior, intermediate and senior faculty members. The model supports strategic decision making in terms of hiring academics.	Research productivity	No.

(continues)

APPENDIX II (continues)

Evaluation for University Scientific Research Capability based on FCE (Liu and Shi, 2008)	Fuzzy Comprehensive Evaluation	In order to assess scientific research productivity of a university, an evaluation model was introduce that is based on evaluation indexes and has a score showing overall research capability as the output.	Research capability	Yes. We can assess university's research performance.
Fuzzy Comprehensive Evaluation Model of Core Competitiveness (Song and Liu, 2009)	Fuzzy Comprehensive Evaluation	A model for the assessment of university's competitiveness.	Core competitiveness of university	Yes.
A Genetic Algorithm Method to Fuzzy Goal Programming Formulation Based on Penalty Function for Academic Personnel Management in University System (Pal, Chakraborti and Biswas, 2010)	Fuzzy Goal Programming Genetic Algorithm	A model is used for effective resource and staff allocation in university's departments.	Resource allocation Staff allocation	No.
Modelling institutional behaviour: A microeconomic analysis of university management (Borooah, 1994)	Mathematical modelling	A mathematical model for optimal resource allocation between teaching and research activities in university.	Resource allocation	No.
An Empirical Research of Integrated Educational Management for the Universities (Habib and Jungthirapnaich, 2010a)	Structural Equation Modelling	A model identifies the major factors of educational institution affecting university's education and research outcomes such as graduates and research productivity.	Research outcomes Graduates	No.

(continues)

APPENDIX II (continues)

Research Framework of Educational Supply Chain Management for the Universities (Habib and Jungthirapnaich, 2009)	Supply Chain Management	A conceptual model where university is presented as a service provider by means of the Supply Chain Management model.	Research outcomes Graduates	No.
An Empirical Research of Educational Supply Chain for the Universities (Habib and Jungthirapnaich, 2010b)	Structural Equation Modelling	A model identifies the key elements of educational SCM having an impact on university's performance and society's wellbeing.	Research outcomes Graduates	No.
Application of entropy model to evaluate order degree of university management structure (Wang and Zhao, 2009)	Entropy evaluation model	A mathematical model to assess university system's order degree in terms of timeliness and veracity of the management process.	Timeliness Veracity	Yes. The model evaluates management processes in universities and proposes the improvements by reducing the number of executive branches.
Developing a Framework for a Viable Research University (Adham et al., 2015)	System thinking Viable system model	A generic model of university that shows the interconnection between all university function and the administration.	Generic view The functions of university management	No.

(continues)

APPENDIX II (continues)

Developing Performance-Oriented Models for University Resource Allocation (Casper and Henry, 2001)	Mathematical modelling with objective and weight variables	A mathematical model supporting the allocation of equipment and finances between university departments.	Resource allocation	No.
Faculty Sufficiency And AACSB Accreditation Compliance Within A Global University: A Mathematical Modeling Approach (Boronico, Murdy and Kong, 2014)	Linear programming	A mathematical model for optimal faculty staff allocation to ensure faculty sufficiency requirements.	Resource allocation	No.
Research on an empirical research program of university organizational performance assessment (Wu et al., 2010)	Fuzzy analytic hierarchy process	A mathematical model to evaluate university's performance.	University performance	Yes.
Value-based performance excellence model for higher education institutions (Ab Hamid, 2014)	Structural Equation Modelling	A model to assess university performance based on six key factors.	University performance	Yes.
A dynamic model of generating the payroll of the academic teaching staff in higher educational institutions (Kizatova, 2016)	Mathematical dynamic modelling	A dynamic model for fund allocation between university departments.	Resource allocation	No.

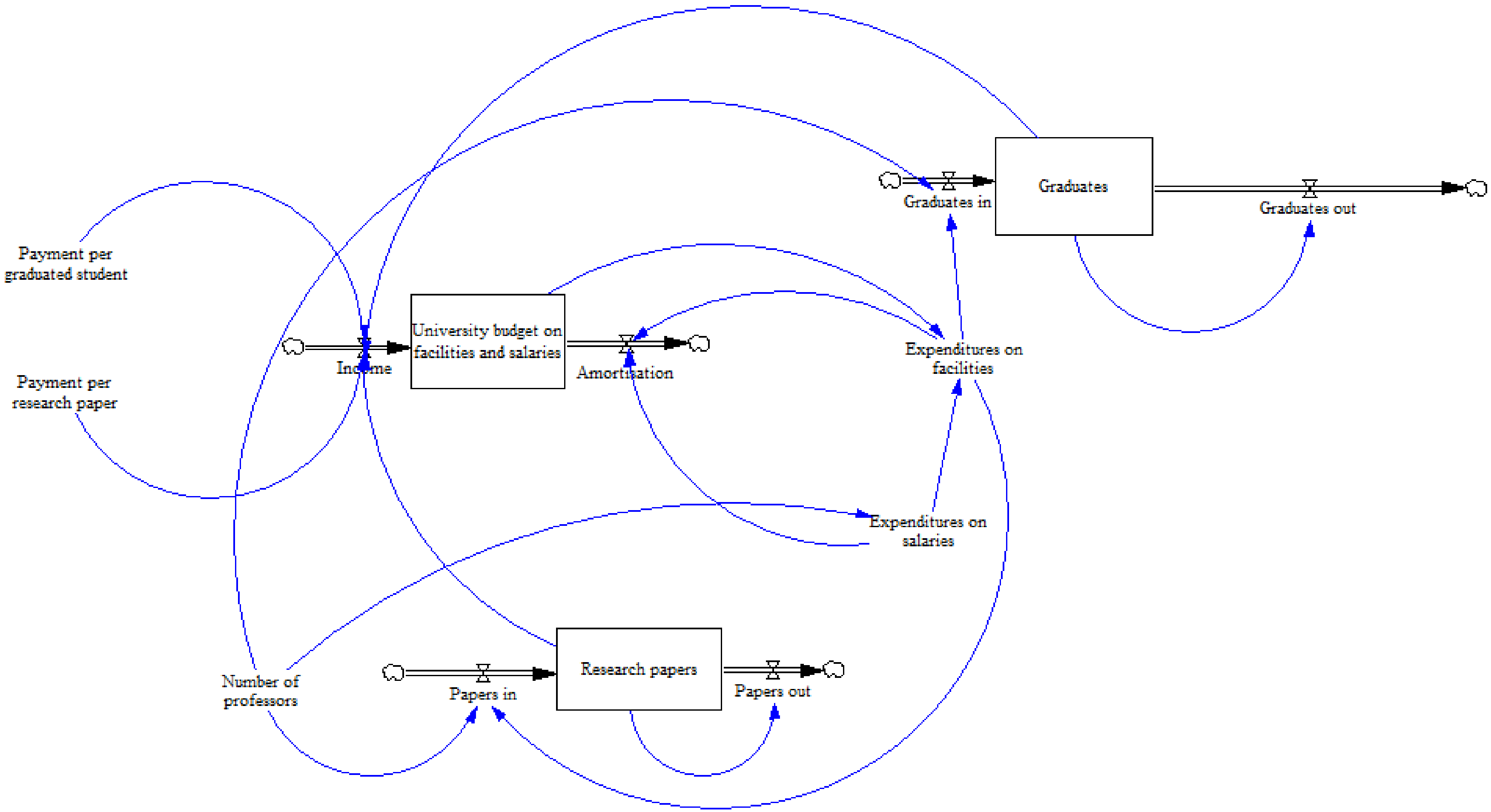
(continues)

APPENDIX II (continues)

[Formation of research university: financial structure and terms of employment.] Postroenie issledovatelskogo universiteta: struktura finansirovaniya i usloviya najma professorov (Sonin, Khovanskaya and Yudkevich, 2008)	Mathematical dynamic modelling	A dynamic model for university recruitment that identify an optimal number of high-quality professors and students in a university. It also allows choosing a strategy for the formation of a research university in the conditions of budget uncertainty.	Staff allocation	No.

APPENDIX III

Stock and flow diagram.



APPENDIX IV

The data provided by Lappeenranta University of Technology.

Year	Professors (FTE)	Number of associate professors	Number of PhD students	University bachelor degree	Higher university degree (Master)	Higher university degrees (Master)	Number of students accomplished 55-credits in each year	Peer-reviewed scientific publications
2000	58,9	N/A	100	24	3897	386	N/A	N/A
2001	64,7	N/A	159	0	4257	363	N/A	N/A
2002	71,8	N/A	222	0	4568	467	N/A	N/A
2003	76,7	N/A	278	0	5018	433	N/A	N/A
2004	85,9	N/A	351	0	5251	470	N/A	N/A
2005	88,9	N/A	390	497	4502	492	N/A	N/A
2006	87,5	N/A	393	1066	3998	517	1292	N/A
2007	82,2	N/A	485	1528	3617	638	1555	N/A
2008	83,4	N/A	456	2215	2801	770	1689	N/A
2009	79,8	N/A	490	2337	2798	609	1720	N/A
2010	80,2	44,6	467	2906	1825	872	1882	555
2011	85,1	88,2	340	2697	1925	573	1595	693
2012	81,2	92,4	365	2573	1966	588	1611	672
2013	82,8	96,4	385	2465	1955	615	1474	838
2014	83,3	105,1	542	2486	1936	584	1464	867
2015	73,6	107,2	496	2467	1886	596	1554	916
2016	69,6	100,3	415	2410	1984	575	1681	814