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Zilla Sinuany-Stern *Editor*

Handbook of Operations Research and Management Science in Higher Education

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Zilla Sinuany-Stern
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Handbook of Operations Research and Management Science in Higher Education

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Editor
Zilla Sinuany-Stern
Department of IEM
Ben-Gurion University of the Negev
Beer-Sheva, Israel

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Preface

This handbook highlights the potential to apply the various *operations research* (OR) and *management science* (MS) models in all functional areas and levels of higher education (HE). OR is “a unique combination of mathematics, statistics, and computers—to assist in decision making for complex organizational problems,” as described on the website of the first university in the world to grant a doctorate in this field—Case Western Reserve University in Cleveland, Ohio (accessed in June, 2020, https://weatherhead.case.edu/degrees/doctorate/phd/operations-research/). OR is the original term used upon its inception during World War II where it was utilized to improve military operations. Its synonym, MS, points at OR’s managerial orientation in general, as applied to business, industry, and various types of organizations including HE. Other synonyms for OR include *decision science*, *systems analysis*, *operations management, analytics,* and more. We believe that researchers in this field have, in their own HE institution, an immediate framework for applying its methods, demonstrating to their administrators and students OR’s effectiveness in improving their own department, school, or institution.

From time to time, discussions revolve around whether HE should be considered a product (see Chap. 1, Sect. 4.1). Does it behave as a non-profit organization or is it becoming a for-profit organization? The 16 chapters in this handbook address this question from various angles.

The chapters of this book are divided into three parts:

Part I: Reviews and Overviews
Part II: New Methodologies
Part III: Applications

The Contents

Part I includes 9 chapters (Chaps. 1, 2, 3, 4, 5, 6, 7, 8, and 9) of reviews and overviews of OR methods and specific functional areas that have been central in HE since the turn of the millennium.

Chapter 1, by Sinuany-Stern, overviews OR in HE in 40 major OR journals. In a search in the Web of Science, out of 58 OR methods, the *simulation* method appeared most often in articles' topic, and out of 30 HE functional areas, *strategy* appeared most often. Moreover, reviewing OR methods *by* functional area, the leading combination in the number of articles was *the data envelopment analysis* (DEA) by the *efficiency* area.

Chapter 2, by Oplatka and Hemsley-Brown, systematically reviews the literature of HE *marketing* between 2005 and 2019, pointing to five major themes: *the marketization of HE; marketing communications; branding, image, and reputation; marketing strategy; and recruitment, alumni, and gift-giving*. Marketing has become a central tool in HE strategy for recruiting students. Almost 44% of the 105 articles reviewed used quantitative methods.

Chapter 3, by Tiram and Sinuany-Stern, suggests a new classification of HE *simulation* methods into two main types: *analytic simulation* used mainly for planning purposes, and the more widely used *educational simulators and games*. The *analytic simulations* include discrete-event simulation and *Monte Carlo*, *agent-based simulation*, and *system dynamics*. The *educational simulations* include *virtual reality, educational games, simulators, and manikin*.

Chapter 4, by Yair, argues that robust HE *information systems* are crucial for decision makers at all academic levels and for analytical analysis. He describes the reasons for the failure of Current Research Information Systems (CRIS) to modernize routine managerial tasks involved in academic administration and suggests ways to close the gap to modernize academic decision making in universities.

Chapter 5, by Sinuany-Stern, is an overview on *forecasting*, suggesting a new classification of HE forecasting methods into two main groups: *passive* and *active* methods. It presents the change in the twenty-first century from passive predictions via ratio methods and time series analysis to active targeted forecasts via marketing, causal regression, and data mining—aimed mainly at achieving a targeted planned enrollment and retaining existing students from dropping out.

Chapter 6, by Pino-Mejias and Lukue-Calvo, presents a benchmarking interactive tool that includes the most likely OR methods for HE administrators: *multivariate statistics*, *analytical hierarchy process (AHP)*, *PROMETHEE,* and *DEA*, with an example given of university ranking. Moreover, for each of the above methods, they provide examples of HE applications from the literature.

Chapter 7, by Sinuany-Stern and Sherman, reviews the literature on *balanced scorecard* (BSC) application in HE *strategic planning*. In the university context, BSC translates the institution's mission statement and strategy into specific measurable goals (e.g., number of students and graduates, number of publications) and monitors the organization's performance regarding achievement of these goals.

Chapter 8, by Bentur, Getz, and Shacham, provides a systems analysis of *Technology Transfer Office* that is needed in universities to control *industry relations*, e.g., research funding and technology commercialization. They present examples of technology transfer in the fields of artificial intelligence, data science, and smart robotics, recommending that universities' achievements regarding the third mission (technology transfer) should be quantified and ranked on national and international levels.

Chapter 9, by Sinuany-Stern, presents an *optimization simulation scheme* for *budget planning* in HE. A variety of budgeting procedures, along with cost simulation, and mathematical models for budget allocation from the literature are presented, such as *linear programming and quadratic programming* with intuitive solutions for most of the models presented for non-quantitative administrators.

Part II of the handbook includes 3 chapters (Chaps. 10, 11, and 12) on specific methodological advancements in HE, giving OR-oriented readers examples of theoretical models.

Chapter 10, by Keren, Hadad, and Minchuk, develops a unique *game theory* model for *allocating* a research budget among several academic departments (the contestants). The prize for this contest is the desired research budget. Moreover, a new *bargaining* model is also developed. A numerical example demonstrates the model and its applicability.

Chapter 11, by Leite, Melicio, and Rosa, deals with an *examination timetabling* problem—a famous problem that in HE practice becomes too large to reach an optimal solution in reasonable computer running time; thus, an accelerated variant of the *threshold acceptance* (TA) algorithm called *Fast TA* is developed here. Its efficiency is measured in relation to other known algorithms, utilizing the known Toronto and ITC 2007 benchmark sets for comparison—showing significantly less running time for Fast TA.

Chapter 12, by Sinuany-Stern and Friedman, develops a *robust* method to identify the best *rank-scaling efficiency* from several efficiency methods, based on the maximum average correlation of each rank-scale method with all the others. The method is exemplified using data from a previous article on academic departments at a given university. The scale-ranking methods used in the example are *DEA super efficiency, DEA cross efficiency, discriminant analysis, and canonical correlation*.

Part III of the handbook includes 4 chapters (Chaps. 13, 14, 15, and 16) on specific case studies, applying OR methods in various functional areas and levels for HE institutions.

Chapter 13, by Sitaridis, Kitsios, Stefanakakis, and Kamariotou, uses *preference disaggregation analysis*, a *multi-criteria approach*, to evaluate an *ICT* course in Greece by students utilizing a course experience questionnaire with 36 items. This method supports educators in organizing a course more flexibly and facilitates student communication with teachers and their more active participation in the educational process.

Chapter 14, by Pietrzak, applies the *balanced scorecard* (BSC) for *strategic planning* at a Polish university, tracking its development over 10 years of major changes in the Polish HE system while highlighting the difference between businesses and HE in applying BSC, and the adaptations needed in HE.

Chapter 15, by Davidovitch and Wadmany, reports on the perception of students and lecturers on using *E-learning* (mainly the Zoom platform) during the COVID-19 pandemic in Israel. They used *questionnaires* distributed to a variety of Israeli HE institutions and used *statistical testing* and *regression analysis*. Their main finding is that less than half of the students and about a third of the lecturers were satisfied with E-learning.

Chapter 16, by Sinuany-Stern and Hirsh, is a case study devoted to the *relative efficiency* of HE in 29 *OECD* countries based on their 2019 data of selected HE inputs and outputs. The efficiency of spending public resources on HE at the national level is of key interest in the context of accountability, especially in developed countries. The robust method from Chap. 12 is applied. In the study, based on two inputs and six outputs, the USA ranks as the country that is most efficient.

For each of the 16 chapters, Table 1 lists all author's last names, the OR method(s) used, and the functional areas of HE for which each method is used.

In Summary

The content of this handbook is evidence that the third HE revolution is at its height (Chap. 1, Sect. 4.5), namely that the HE sector has both business and for-profit characteristics such as marketing (Chap. 2), measuring customer satisfaction (student course evaluations in Chaps. 13 and 15), strategic planning via BSC (Chaps. 7 and 14), managing HE research performance (Chap. 4), business relations with industry (technology transfer, Chap. 8), ranking in HE (Chaps. 6, 12, and 16), internationalization (Chap. 1, Sect. 4.4) and E-learning (Chap. 15), which is the highlight of the 4.0 industrial revolution, supported by educational web-based simulators (Chap. 3), and measuring HE efficiency (Chap. 16). Intertwined with the main classical areas of HE planning are simulation (Chap. 3), forecasting (Chap. 5), planning and budgeting (Chap. 9), resource allocation (Chap. 10), and examination timetabling (Chap. 11).

This handbook on OR and MS in HE is an essential tool for planning in all areas and levels at any time, just as in any other business and industry, and even more so in times of crisis such as during the COVID-19 epidemic.

Audience

This book is aimed at HE administrators, business administration graduates, management scientists, operations researchers, analytic and industrial engineers, applied mathematicians, and computer scientists at all levels who are interested

Table 1 List of chapters with OR/MS[a] method used and HE[a] functional areas to which they apply

Chapter	Author(s)	OR/MS method(s) applied[a]	HE functional area
Part I Reviews and Overviews			
1	Sinuany-Stern	58 OR/MS methods	30 HE functional areas
2	Oplatka and Hemsley-Brown	Questionnaires and multivariate statistics	Marketing
3	Tiram and Sinuany-Stern	Analytic simulation and educational simulators	Planning, training, and labs
4	Yair	Research information systems	Improving academic management
5	Sinuany-Stern	*Passive* versus *active* forecast: time series, regression, data mining	Forecasting of costs, income, enrollment, faculty, etc.
6	Pino-Mejías and Luque-Calvo	PCA, PROMETHEE, and DEA	University ranking, benchmarking
7	Sinuany-Stern and Sherman	Balanced scorecard	Strategic planning
8	Bentur, Getz, and Shacham	Systems analysis	Technology transfer
9	Sinuany-Stern	Linear programming and quadratic model	Planning, budgeting, cost simulation
Part II New Methodologies			
10	Keren, Hadad, and Minchuk	Game theory and AHP	Funding research
11	Leite, Melício, and Rosa	Fast threshold acceptance algorithm	Examination timetabling
12	Sinuany-Stern and Friedman	Robust rank-scale, correlation, DEA, multivariate statistics	Robust efficiency of academic departments
Part III Applications			
13	Sitaridis, Kitsios, Stefanakakis, and Kamariotou	Multi-criteria analysis, disaggregation analysis	Course evaluation and satisfaction of ICT
14	Pietrzak	Balanced score card	Strategy in a Polish HEI
15	Davidovitch and Wadmany	Questionnaire, regression, statistical testing	E-learning in HEIs in COVID-19 crisis effectiveness in Israel
16	Sinuany-Stern and Hirsh	DEA, multivariate statistics, robust scale	Efficiency of OECD countries in HE

[a]*HE—higher education, HEI—HE institution, OR—operations research, MS—management science, ICT—information and communications technology, PCA—principal component analysis, DEA—data envelopment analysis, PROMETHEE—Preference Ranking Organization Method for Enrichment Evaluations, AHP—analytic hierarchy process, OECD—Organisation for Economic Co-operation and Development*

in contributing to the enhancement of the HE system. Each of these individuals will find chapters fitting their level, as most are overviews and are not quantitative. Moreover, the chapters are independent of each other and cover many planning areas in HE and OR/MS methods.

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Zilla Sinuany-Stern

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About the Editor and Contributors

About the Editor

Zilla Sinuany-Stern is a Professor Emerita in the Department of Industrial Engineering and Management (IEM) at Ben-Gurion University (BGU) of the Negev in Israel. Dr. Sinuany-Stern has served in many administrative roles in HE: as the Head of IEM at (1000 students) and as a member and chair of various important committees at the university. In an interim period of 8 years, she was the Provost of Ariel University (8000 students at that time). On the national level, she was the President and VP of the Israel Society of OR for 8 years, and for 5 years (until 2017), she was a member of the Council for Higher Education of Israel, also chairing its Quality Assurance Committee. At the international level, she was Vice President of the European Association of OR (EURO) for 4 years. She has been a member of the International Advisory Board of the *Journal of the Operational Research Society* since 1993 (in the UK, the first OR journal ever, opened in 1950). Sporadically, over the years, she has consulted for various public authorities in Israel and for HE institutions in the USA such as the Commission for HE in Indiana. She received her PhD in OR from Case Western Reserve University in 1978 and her BA and MA from Tel Aviv University in economics and statistics.

Contributors

Arnon Bentur Samuel Neaman Institute, Haifa, Israel

Nitza Davidovitch School of Education, Ariel University, Ariel, Israel

Lea Friedman Department of Industrial Engineering & Management, Ben Gurion University of the Negev, Beer Sheva, Israel

Daphne Getz Samuel Neaman Institute, Haifa, Israel

Yossi Hadad Department of Industrial Engineering and Management, SCE—Shamoon College of Engineering, Beer Sheva, Israel

Jane Hemsley-Brown Surrey Business School, University of Surrey, Guildford, UK

Arthur Hirsh Webster Vienna Private University, Vienna, Austria

Maria Kamariotou Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece

Baruch Keren Department of Industrial Engineering and Management, SCE—Shamoon College of Engineering, Beer Sheva, Israel

Fotis Kitsios Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece

Nuno Leite Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Lisboa, Portugal

LARSyS—Laboratory for Robotics and Systems in Engineering and Science, Universidade de Lisboa, Lisboa, Portugal

Pedro-Luis Luque-Calvo Departamento de Estadística e Investigación Operativa, Universidad de Sevilla, Seville, Spain

Fernando Melício Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Lisboa, Portugal

LARSyS—Laboratory for Robotics and Systems in Engineering and Science, Universidade de Lisboa, Lisboa, Portugal

Yizhaq Minchuk Department of Industrial Engineering and Management, SCE—Shamoon College of Engineering, Beer Sheva, Israel

Izhar Oplatka School of Education, Tel Aviv University, Tel Aviv, Israel

Michał Pietrzak Institute of Economics and Finance, Warsaw University of Life Sciences, Warsaw, Poland

José-Luis Pino-Mejías Departamento de Estadística e Investigación Operativa, Universidad de Sevilla, Sevilla, Spain

Agostinho C. Rosa Department of Bioengineering/Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

LARSyS—Laboratory for Robotics and Systems in Engineering and Science, Universidade de Lisboa, Lisboa, Portugal

Oshrat Katz Shacham Samuel Neaman Institute, Haifa, Israel

H. David Sherman DMSB—Northeastern University, Boston, MA, USA

Zilla Sinuany-Stern Department of Industrial Engineering & Management, Ben Gurion University of the Negev, Beer-Sheva, Israel

Ioannis Sitaridis Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece

Stavros Stefanakakis Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece

Efrat Tiram Sackler Faculty of Medicine, Tel Aviv University, Ramat Aviv, Tel Aviv, Israel

Rivka Wadmany The Council for Higher Education, Jerusalem, Israel

Gad Yair Department of Sociology and Anthropology, The Hebrew University of Jerusalem, Jerusalem, Israel

Part I
Reviews/Overviews

Chapter 1
Operations Research and Management Science in Higher Education: An Overview

Zilla Sinuany-Stern

Abstract Operations Research (OR) is an interdisciplinary discipline that evolved during WWII to solve complex operational military problems such as scarce resource allocations and logistics. Thereafter, it has been used successfully in the private and public sectors—including in higher education (HE). The purpose of this chapter is to give an overview of the use of OR methodologies in HE and the functional areas in which they are used. First, a search in 40 OR journals reveals that HE and OR methodology appeared in the title of 0.3% of their articles during 1950–2019. Moreover, in 17 OR journals, HE did not appear in any article. Second, looking at the web of science during 2000–2019, we identified 58 main OR methods relevant to HE. Leading these methods (in terms of the number of articles) is *simulation*. Third, we identified 30 functional areas relevant to HE. Leading these areas is *strategy*. For specific methods by area, the leading combination is *data envelopment analysis* by *efficiency*. In summary, there is great potential for academics in OR to utilize OR models to improve their own HE system, especially during and after crises such as a pandemic.

Keywords Higher education · Operations research · Management science · Overview

1.1 Introduction

Operations Research (OR) and Management Science (MS) aid decision-makers in business, industry, government, and *academia*, putting emphasis on the strong relationship of OR with computer science, information systems, and mathematics (Gass & Fu, 2013).

Z. Sinuany-Stern (✉)
Department of Industrial Engineering & Management, Ben-Gurion University of the Negev, Beer Sheva, Israel
e-mail: zilla@bgu.ac.il

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Operations research began during World War II, first in the UK and then in the USA, in a cooperative effort to solve complex military decisions such as radar locations, allocation of supplies and ammunition, game theory (war games), and logistics. Hartcup (2000) wrote about the: "Birth of a new science: operational research" as one of the outcomes of applying science in World War II.

The OR/MS profession is unknown to many—sometimes even in academia, as well as in other disciplines. The president of IFORS (International Federation of Operations Research), representing 40,000 members worldwide, acknowledged that he finds it hard to explain exactly what "Operational Research" is; moreover, the history of OR has had many proposals for new names, embracing various buzzwords—the latest one is "Analytics" (Trick, 2018). The main other terms used for OR are Operational Research (UK) Operations Research (US), Management Science (US in schools of business), Decision Science (NSF), Scientific Management, Operations Management, Systems Analysis, and Analytics.

Indeed, to solve real-life complex problems that managers often face, the mathematical models representing the problem are large, with many constraints under uncertainty, and often have no closed-form solution. Thus, computerized algorithms are often required, and good computerized management information systems (MIS) are crucial for the success of OR. OR has been applied in many areas to date, such as in business, industry, the public sector, healthcare, transportation, and education.

Education is one of the major components in measuring the Human Development Index (HDI) of nations. Since 2010, the UN has used HDI to measure a country's development. The index comprises three indicators: 1. life expectancy, 2. education (years of schooling), and 3. per capita income (GNI in PPP). (UN; accessed in June 2020, http://hdr.undp.org/en/countries). Higher Education (HE) is the highest level of education. According to the World Bank (2020), this term refers to all post-secondary education, including colleges, technical training institutes, and vocational schools. HE is instrumental in fostering growth, reducing poverty, and boosting shared prosperity. A highly skilled workforce with a solid post-secondary educational level is a prerequisite for innovation and growth, based on the assumption that well-educated people are more employable, earn higher wages, and cope with economic shocks better (World Bank; accessed on Feb. 2020, https://www.worldbank.org/en/topic/tertiaryeducation).

The transformation of the industrial era into the information age has changed the basis of competitive advantage from a financial and physical resource-based economy to one that is intellectual and knowledge-based (Stewart, 1997). This change has placed universities in a central position to produce economic benefits. As the springs of knowledge and places that produce knowledgeable beings, along with the advancement of technology, universities have a vital role in determining the wealth of a nation, especially today, when HE is one of the major enterprises producing the most precious product—knowledge.

Already in the 1970s, HE institutions (HEIs) were described as organized anarchy (Cohen & March, 1986) with weak regulation and inadequate control. Schierenbeck (2013) claims that HE across the globe is in a productivity crisis that prevents broad access to affordable and high-quality educational services. He suggests closing the productivity gap in HE by academic managers using some managerial practices applied by the world's leading business enterprises. HEIs that generate knowledge to foster productivity are often unproductive—"the shoemaker's children have no shoes." In academic circles, often the topic of productivity is widely considered "a taboo subject" (ibid.).

Along with this progress, public demand for accountability in HE is increasing. OR offers various types of models for improving HE management at all levels of HEIs from the department level to the national and international levels. The application of OR in education was pointed at from its initiation by the first OR journal *JORS* (originally called *OR Quarterly*) as an applied research field. The purpose of this chapter is to give an overview of the use of OR methodologies in HEIs, and the functional areas in which they are used.

Other books and review papers were devoted to OR in HE from the beginning (such as Terrey, 1968; Schroeder, 1973; Cheng, 1993; Johnes, 2015); however, their scope is quite limited compared to the 58 OR/MS methods and 30 functional areas covered in this review in the web of science (WoS), as listed in Appendices 2 and 3.

Section 1.2 of this chapter reviews the appearance of HE articles in the main 40 OR journals from the WoS. Section 1.3 covers the appearance of 58 OR methods (clustered into ten groups) in all WoS journals and 30 functional areas applied to HE (clustered into four groups). Section 1.4 covers several HE issues. Finally, Sect. 1.5 concludes and draws future research directions for OR in HE.

1.2 OR/MS Publications

In academia, sometimes OR courses are given in various departments/schools such as Mathematics, Business, Economics, Industrial Engineering, Statistics, Computer Science, Electrical Engineering, Logistics, and Supply Chain. In some HEIs, the teaching of OR is not taught in a separate OR department but is included in one or more of the above departments.

The first OR journal was the *Journal of the Operational Research Society* (*JORS*). It was first published in 1950 by the UK OR Society (and was called: *A Quarterly Journal of OR* until 1976). In the beginning, only abstracts (extended) of OR papers were published, collected "*from as wide fields as possible*," including education (Editorial Notes, *JORS*, 1, 1950). The interdisciplinary nature of OR was expressed there as follows: "*Operational research shares with other branches of science . . . in knowledge and technique. Studies in social science, . . . , productivity studies, education, etc., have common features*." This was the justification for the first OR journal, *JORS*—the emergence of a new discipline (I am honored to have been on the international advisory board of JORS since the early 1990s). Today in the WoS alone, there are over 75 OR/MS journals.

One of the first books that started shaping OR discipline was by Churchman et al. (1957), along with other major books such as Hillier and Lieberman (2014, 10th edition), Winston (2004, 4th edition), and Taha (2017, 10th edition) who included the main OR methodologies such as linear programming, transportation models, network optimization, scheduling, integer programming, goal programming, non-linear programming, dynamic programming, metaheuristics, game theory, queuing theory, decision analysis, inventory theory, Markov decision processes, queuing theory, forecasting models, and simulation.

In a bibliometric general review of OR, Merigo and Yang (2017) concluded that the American School of OR leads the most influential analysis of OR and MS in general, based on parameters such as the number of citations in OR journals from the WoS. They identify the leading countries in OR/MS as follows: leading is the American School with the two most influential journals in the field: *Management Science* and *Operations Research*. Moreover, Americans have published most of the leading articles thus far. They are followed by Continental Europe (*EJOR*), China (with several leading researchers), and the British School (*JORS*).

1.2.1 Reviews on OR in HE

Already in 1968, it was claimed that HE was a complicated business. Terrey (1968), in his review of HE management tools (for the period 1963–1968), highlighted four techniques: a. the program planning budgeting system (PPBS), b. systems analysis, c. CPM/PERT, and d. the Delphi Technique. He stated that budgeting is both a science and an art (ibid.). Schroeder (1973), in a review of the literature on MS in university operations, listed four main areas: a. PPBS, b. management information systems, c. resource allocation models, and d. mathematical models. He concluded there were four problem areas in HE at that time: student flow projections, information to be used in decision-making processes, measurement of outputs, and alternative improved planning methodologies (ibid.). Cheng (1993) focused on summarizing 15 papers on various OR models applied in HE covering the following main areas: a. resource allocation, b. budgeting, c. project group formation, d. scheduling courses and examinations, e. classroom allocation, f. student registration, g. tuition and fee structures, and h. the Ph.D. submission rate. This review concluded that while in the 1960s and 1970s OR models applied mainly LP, in the 1980s, goal programming was mostly used, and most published papers were financial planning models. However, Cheng (1993) claims that models for budgeting were implemented more often than resource allocation. He points at the often-used scheduling problems such as classroom allocation and examination and course timetabling, ranging from manual procedures to fully automated systems. He blames the lack of application on the communication gap between OR analysts and academic administrators (ibid.).

Johnes' (2015) review is devoted to education in general but also relates to HE. This review includes over 200 papers covering mainly the following areas: a. planning, b. resource allocation, c. efficiency and performance measurement, d.

vehicle routing and scheduling, e. the assignment problem, f. student grouping, and g. examination scheduling and course timetabling.

Bell et al. (2012) edited a book on HE management and OR that covers various important issues. Some are rather philosophical, such as the various metaphors for HE management, questioning the use of industrial approaches to quality in HE, HE management and university culture, and web-based learning. The major OR method for which two full chapters were devoted is system dynamics. Overall, their book deals more with soft OR. It fits the less mathematically oriented administrator (ibid.).

The review in the next section counts the number of HE applications in 40 of the main OR journals over time, while Sect. 1.3 covers most of the above OR methods and others (58 OR methods) and more functional areas in HE (30). Most of the above OR methodologies and areas are included.

1.2.2 HE in OR Journals

Various OR journals have different subareas ("departments") listed for paper submission. The Institute for Operations Research and the Management Sciences (INFORMS) publishes 16 refereed journals, for example, INFORMS' journal *Management Science* has numerous departments for paper submissions: Accounting, Big Data Analytics, Business Strategy, Decision Analysis, Entrepreneurship and Innovation, Finance, Healthcare Management, Information Systems, Marketing, Operations Management, Optimization, Organizations, Revenue Management and Market Analytics, and Stochastic Models and Simulation. The other main journal of INFORMS, *Operations Research's* submission departments include Decision Analysis, Environment, Energy and Sustainability, Financial Engineering, Machine Learning and Data Science, Revenue Management and Market Analytics, Military and Homeland Security, Operations and Supply Chains, Optimization, OR Practice, Policy Modeling and Public Sector OR, Simulation, Stochastic Models, and Transportation.

Table 1.1 summarizes the number of articles with HE mentioned in their title in 40 OR journals from the WoS during the period 1950–2019 in comparison to the total number of articles. The journals are grouped into five subgroups according to the range of years when they began publishing. In addition, the same data for the period 2000–2019 is given. A detailed list of the 40 journals with the same data for each journal appears in Appendix 1. The largest number of journals were established before 1980 (16). During this period of 70 years, 352 articles were published in all 40 journals on HE according to the WoS; namely, in the titles of these papers, at least one of the following synonyms for HE appeared: higher education, tertiary education, university, college, or academic. The total number of articles in the journals is 114,698. Thus, HE articles are a mere 0.3%. The journals that began before 1980 published more than half of the total number of articles (71,620) and more than half of the HE application articles (194). In the last 20 years,

Table 1.1 Number of OR/MS journals opened over time from a selected 40 OR/MS journals[a] in the WoS and number of their articles devoted to HE[b] over time

Year journal began	Number of journals opened	Number of articles published in all journals[a] during 1950–2019		Percent of HE[b] articles from total	Number of articles published in all journals[a] 2000–2019		HE[b] articles % from total	Number of journals with no HE[b] articles during 1980–2019
		Total	Applied to HE[b]		Total	Applied to HE		
1950–1979	***16***	***71,620***	***194***	0.27	***42,397***	***101***	0.24	5
1980–1989	8	18,218	105	***0.58***	13,279	66	***0.50***	2
1990–1999	10	22,328	50	0.22	20,336	41	0.20	4
2000–2009	6	2532	3	0.12	2532	3	0.12	3
2010–2019	0	–	–	–	–	–	–	0
Total	**40**	**114,698**	**352**	**0.31%**	**78,544**	**211**	**0.27%**	**18**

[a]Source: summary from Appendix 1, a full list of the 40 journals, and the data of each is in Appendix 1—each is from the WoS (assessed during Aug. 2020). The bold italics figures are the maximal values of each column. The bold figures in the last row indicates the total for each column

[b]The search HE appearance was done only for article titles. HE synonyms used were: higher education, academic, college, university, tertiary education

more than half of the total articles in relation to the first 50 years (1950–1999)—78,544 articles were published. Similarly, the last 20 years had more than half of the HE applications (211 articles).

As shown in Appendix 1, looking into the number of HE articles in OR journals during 2000–2019, the Pareto rule of 20/80 applies: 20% of the journals (8 out of 40) contain 82% of the articles published on HE (in column 6 of Appendix 1, the sum of the articles in the eight leading journals is 173 out of 211 articles during 2000–2019)—each of these eight journals had more than ten articles over the last 20 years with HE articles. In 17 journals, no HE article was found, in 7, there was only one HE article in each, and in 4 journals, only two articles were found in each. The leading eight journals with at least 10 HE articles in their titles were: *Interfaces* (with 41 articles), *European Journal of Operational Research* (30 articles), *Expert Systems with Applications* (28 articles), *Journal of Operational Research Society* (20 articles), *Management Science* (18 articles), *Omega* (13 articles), *Decision Support Systems* (12 articles), and *Annals of Operations Research* (11 articles).

Indeed, the search performed here was limited to articles where the appearance of HE and its synonyms is only in the title of the article. Very likely, there are more HE applications that our search words did not cover. Nevertheless, it is obvious that OR journals give little attention to HE applications. While our count is a proxy, it is representative. Looking in Google Scholar, for example, at "health" applications, using the synonyms: health, hospital, clinic, or medical in the article titles of the journal *Interfaces* alone during the years 2000–2019, 289 articles were found—many more than the number of articles with HE in their title in all the above 40 journals combined (211).

Note that although INFORM dedicates a specific journal for OR education titled: *INFORM Transactions on Education*, the journal is focused on the teaching aspects of OR in HE, not on the application of OR methods in HE; thus, this journal is not included in the list of the 40 OR journals. Indeed, this journal is devoted completely to the pedagogy of OR/MS, as claimed. However, it is not focused on applying OR/MS in HEIs; in searching in this educational journal during 2000–2019, no article was found with the words "higher education" (or its synonyms) with any of the following OR methodologies: linear programming, timetabling, analytics, data mining, information systems, regression, data envelopment analysis, analytical hierarchical process, balanced scorecard, faculty, planning, budgeting, or forecasting (for each methodology, its conjugations were also used in the search). The term HE (or a synonym) appeared only eight times in the context in which the pedagogical approach was tested or suggested. Only once appeared testing for university hospital operations and budget (Hicklin et al., 2017)—again, a health application rather than a university one.

In summary, over the 70 years since the appearance of the first OR journal, only 352 articles have been published in the 40 journals selected with HE in their title (or its synonyms), which is 0.31% of the total number of articles in these journals. Most of the journals have published one or no articles on HE in the past 20 years. The journal with the maximal number of articles with HE mentioned in the title is *Interfaces*, which is devoted to OR applications.

The next section extends the search to count HE applications in all WoS journals (not necessarily OR journals) by OR method and by functional area.

1.3 OR Methods and Functional Areas in HE: Articles in the WoS

The OR methods solicited for this section are taken from: a. tables of contents of leading introductory OR textbooks, and b. major general OR journals, as noted above, which are relevant to HE, as listed in Appendix 2, including 58 OR methods (e.g., linear programming and integer programming), clustered into ten main groups, as summarized in the upper part of Table 1.2 (details of each group are in Appendix 2). Moreover, 30 functional areas are listed in Appendix 3, where OR methods are applied in HE (such as transportation, marketing, and efficiency) that are clustered into four main groups, as summarized in the second part of Table 1.2. A search was done in all WoS journals in all its disciplines since OR is a multidisciplinary field that draws methods from other disciplines such as optimization (from mathematics), simulation (from industrial engineering), multivariate statistics (from statistics), and expert systems (from computer science). Moreover, OR methods are applied in many other disciplines such as engineering, economics, and business. The count of the number of articles with OR methods and functional areas applied to HE was done either from the title of each article or from its topic ("topic" includes: keywords, abstract, and title). The HE search words (synonyms) are at the bottom of Table 1.1[b].

1.3.1 OR Methods in HE: Articles Frequency

Table 1.2 and Appendix 2 display the number of articles counted from the WoS during 2000–2019 by OR methods. There are five columns as follows:

Column (1) counts for each OR method, its appearance in the article topic in general.
Column (2) counts for each OR method, its appearance in the topic of articles with HE in their title.
Column (3) counts for each OR method, its appearance in the title of articles with HE in their topic.
Column (4) counts for each OR method, its appearance in the title of articles with HE also in their title.
Column (5) is the percentage of column (4) from column (1).

Table 1.2 The number of articles by main OR groups of methods and groups of functional areas in HE during 2000–2019

Method name	Number of articles with: (1) Method in topic	(2) Method in topic[b] & HE in title	(3) Method in title & HE in topic	(4) Method in title & HE in title	(5) Percentage of column (4) from column (1)	(6) Specific method with maximal # of articles from the group for column (4)	(7) Number of articles for method with maximal # of articles in the group for column (4)
A. Group of OR methods							
1. Operations research	236,072	1884	1941	435	0.184	Analytics	352
2. Decision analysis	150,236	981	1383	318	***0.212***	AHP	**156**
3. Mathematical programming	283,038	656	791	219	0.077	DEA	159
4. Discrete optimization	38,722	66	75	19	0.049	Integer program.	18
5. Stochastic	424,449	219	807	48	0.011	Stochastic	21
6. Forecasting	328,003	519	1644	112	0.034	Forecasting	81
7. Simulation	***2,555,896***	1852	***7369***	525	0.021	Simulation	***465***
8. Multivariate statistics	1,340,733	***11,315***	1361	198	0.015	Regression	137
9. Heuristics	277,468	528	829	106	0.038	Heuristics	50
10. Expert systems	324,151	2601	3553	***647***	0.200	Information systems	284
Total A	**5,958,768**	**20,621**	**19,753**	**2627**	**0.045**		**1723**

(continued)

Table 1.2 (continued)

	Number of articles with:						
Area name	(1) Area in topic	(2) Area in topic[b] & HE in title	(3) Area in title & HE in topic	(4) Area in title & HE in title	(5) Percentage of column (4) from column (1)	(6) Specific area with maximal # of articles from the group for column (4)	(7) Number of articles for area with maximal # of articles in the group for column (4)
B. Group of functional areas							
1. Transportation	3,753,957	14,852	16,377	3312	0.088	Networks	2582
2. Industry	1,700,795	13,935	12,072	3357	0.197	Industry	2474
3. R&D	239,074	7432	8136	3315	***1.387***	Entrepreneur	2255
4. Bussiness	***7,599,208***	***52,658***	***40,604***	***9807***	0.129	Internationalization	***4253***
Total B	**13,293,034**	**88,877**	**77,189**	**19,791**	**0.149**		**11,564**

[a]These are groups of methods and functional areas. Detailed methods and areas are in Appendices 2 and 3
[b]Topic is keywords or abstract or title (source: summaries from Appendices 2 and 3)
The bold italics figures are the maximal values of each column. The bold figures in the lust row indicates the total for each column

1.3.1.1 Groups of OR Methods

The first part of Table 1.2 presents ten groups of OR methods (as detailed in Appendix 2). Table 1.2 is formed as the sum of the specific methods of each group taken from Appendix 2. The title of each group is as the first method in the group (e.g., the group simulation is as the first method in the group). The three leading groups of methods (with the maximal number of articles in each column) are:

(a) *Simulation*, which leads in general (2,555,896 articles in Column 1), and for method in the title and HE in the topic (7369 articles in Column 3).
(b) *Multivariate statistics*, which leads for method in the topic and HE in the title (11,315 articles in Column 2).
(c) *Expert system*, which leads for method in the title and HE in the title (647 articles in Column 4).

Column 5 of Table 1.2 shows that *decision analysis* leads in percent of the method and HE in title from the general number of the articles with the method (0.212% of Column 4 from Column 1).

Columns 6 and 7 indicate the specific method in each group of methods that had the maximal number of articles with the method and HE in their titles—*simulation* specific method in HE leads (with 465 articles with *simulation* and HE in their title). We consider Column (4) since the articles in this column are more certain to be devoted to OR in HE than the other columns because both the OR method and HE appear in their titles.

1.3.1.2 Specific OR Methods

The previous Sect. 1.3.1.1, deals with groups of OR methods (Table 1.2), whereas this section deals with specific OR methods from Appendix 2. According to this appendix, the two leading specific OR methods (with the maximal number of articles by column) are:

(a) *Simulation* in general (2,269,462 articles in Column 1), and for method in the title and HE in the topic (6655 articles in Column 3), and for method and HE in article titles (465 articles in Column 4); and.
(b) *Regression analysis* for method in the topic and HE in the title (8088 articles in Column 2).

Column (5) of Appendix 2 shows that *scientific management* leads in percent of the method and HE in title from the general number of the articles with this method (0.873% of Column 4 from Column 1). However, scientific management is the least used term for operations research. Moreover, most synonyms of OR are not used often, rather the specific OR method appears in the title or topic. The new buzzword, “analytics,” used for OR and in other contexts as computer science, is the most common of all OR synonyms over the last 20 years. From the specific OR methods, DEA has the next highest percentage of articles in which HE and method appear in the title (0.79% of Column 4 from Column 1).

Overall, the eleven leading specific OR methods, out of 58 in HE, in Columns 2, 3, and 4 are: *simulation, regression* (including *logistic*), *analytics, information systems, data mining, big data, AHP, forecasting, DEA, and DSS*. The Pareto 20/80 rule holds here, as less than 20% of the methods (18.96%) comprise more than 80% of the articles in Column (2) of Appendix 2 (85.72%). Together, these methods make up most of the articles (over 72%) in all three columns of HE in Appendix 2.

Column (2) is the most representative since HE in the title means that the articles are most likely applied to HE, and the method is likely to appear in the topic (title, keywords, or abstract). Since many HE users (administrators) are not quantitatively oriented, the functional area where the method is used is more attractive to them. Indeed, in the next sections dealing with functional areas, there are many more articles than OR methods.

1.3.2 Functional Areas in HE: Articles Frequency

Table 1.2 and Appendix 3 display the number of articles in the WoS during 2000–2019 by functional area. There are five columns as follows:

Column (1) shows for each functional area its appearance in the article topic ("topic" includes title, abstract, and keywords) in general.
Column (2) shows for each functional area its appearance in the topic of articles with HE in their title.
Column (3) shows for each functional area its appearance in the title of articles with HE in their topic.
Column (4) shows for each functional area its appearance in the title of articles with HE also in their title.
Column (5) is the percentage of column (4) from column (1).

1.3.2.1 Groups of Functional Areas

There are 30 functional areas clustered into four groups. The second part of Table 1.2 presents the four groups of functional areas: *transportation, industry, R&D*, and *business* (as detailed in Appendix 3). For example, the group *transportation* is composed of eight specific areas, of which *networks* has the largest number of articles from all *transportation* specific areas for each of the five columns (as indicated in Appendix 3, and Table 1.2). The title of each group is mostly as one of the areas in the group (e.g., the group t*ransportation* is the first method in the group). The leading group of functional areas (with the maximal number of articles) in all four columns is *business*.

In all the columns of Table 1.2, the total number of articles for functional areas is much larger than the number of articles with OR methods (in Table 1.2, see that the line of Total B versus the line of Total A is more than double in each column).

Column (5) of Table 1.2 shows that *R&D* leads in the percentage of the functional area and HE in the title from the general number of articles with the functional area in their topic (1.387% of Column 4 from Column 1)—indicating that R&D is more central in the HE context than other functional areas in general.

Columns (6) and (7) indicate the specific functional area in each group of methods that had the maximal number of articles with the functional area and HE in their titles. For the leading group *business*, *internationalization* is the specific functional area in HE that leads (4253 articles with internationalization and HE in their title).

1.3.2.2 Specific Functional Areas

In Appendix 3, the three leading *specific* functional areas (with the maximal number of articles for each column) are:

(a) *Strategy* for the functional area as the topic and HE in the title (16,261 articles in Column 2, and 12,151 articles in Column 3).
(b) *Internationalization* for functional area and HE in the title (4253 articles in Column 4).
(c) *Efficiency* in general (2,643,368 articles in Column 1).

Overall, the eight leading functional areas in HE in all three Columns 2, 3, and 4 (in order of Column 3) are *strategy, networks, internationalization, industry, marketing, efficiency, entrepreneurship*, and *finance*.

Column (5) of Appendix 3 shows that *timetabling* leads in the percentage of the functional area and HE in the title from the general number of articles with the functional area as their topic (11.56% of Column 4 from Column 1)—indicating that timetabling is more central in the HE context than in general—often applied for the course or examination timetabling.

1.3.3 Group of OR Methods by Group of Functional Areas

Not all articles with HE and functional areas include an OR method, thus, we looked at those that mention both: OR method and area. Table 1.3 presents the ten OR groups of methods (appearing in the title) by four groups of functional areas (appearing in the topic) that are applied to HE (in the title). The leading OR group of methods is: *mathematical programming* by *business* as the functional area (with 213 articles), where the total number of articles of the leading group of methods is *mathematical programming* with 298, and the number of articles of the leading group of functional areas is *business* with 606 articles, as highlighted in Table 1.3.

Table 1.3 Number of articles with OR groups of methods[a] by groups of functional areas[b] in HE[a] during 2000–2019

	Areas of application					
	Transportation	Industry	R&D	Business	Total	% from total
OR group of methods						
1. Operations research	7	20	2	42	**71**	6.1
2. Decision analysis	40	29	12	73	**154**	13.1
3. Mathematical programming	40	30	15	***213***	***298***	25.5
4. Discrete optimization	12	0	0	6	**18**	1.5
5. Stochastic	2	3	1	11	**17**	1.5
6. Forecasting	12	5	3	20	**40**	3.4
7. Simulation	52	33	10	86	**181**	15.5
8. Multivariate statistics	26	15	4	31	**76**	6.5
9. Heuristics	42	2	0	17	**61**	5.2
10. Expert systems	103	35	25	117	**280**	21.7
Total	**336**	**172**	**72**	***616***	**1196**	100
% from total	28.1	14.4	6.0	51.5	100	

[a] The bold figures indicate the totals of each row and each column. The bolditalic figure within the table indicate the maximal value, and its row and column's totals
[b] Appears in the topic (assessed from WoS during Sept. 2020)

1.3.4 Specific OR Methods by Specific Functional Areas

Table 1.4 provides a deeper look at 12 selected specific OR methods in HE (out of 58 in Appendix 2) by eight selected specific functional areas in HE (out of 30 in Appendix 3). Note that in Table 1.4, the method appears in the topic (title, keywords, or abstract) and HE, and the specific functional area appears in the title of the articles. First, the group of methods with at least 50 articles in Table 1.3 was selected. Thus, from 10 groups of methods, only seven were considered (1, 2, 3, 7, 8, 9, and 10). Each of these seven groups has at least 50 articles. From the selected groups, the methods—in total 12 such specific methods were selected—with the largest numbers in Column (2) of Appendix 2 (as listed in Table 1.4). Similarly, for the group of functional areas, the two largest were selected from Table 1.3 (with more than 200 articles). The selection of the specific areas is based on Appendix 3.

Looking into the 12 leading specific OR methods in Table 1.4, the table is not as consistent as Table 1.3, since the entry with the maximal number of articles by method and functional DEA by efficiency (with 170 articles) is not the intersection of the OR method with the maximal number of articles (*regression* with 341 articles) or the functional area with the maximal number of articles (*network* with 269 articles). Thus, as highlighted in Table 1.4, we point at three leading methods:

DEA by *efficiency* is the leading combination of specific OR methods and specific functional areas (with 170 articles). This is consistent with the leading combination in Table 1.3, where *mathematical programming* by *business* leads, as *DEA* is a specific method of mathematical programming and *efficiency* is a sub-area of

Table 1.4 Number of articles in major OR/MS-specific methods[a] by specific functional area in HE during 2000–2019

	Title								
	Network	Time tabling	Marketing	Finance	Strategy	Efficiency	Accounting	International	Total
Topic									
Analytics	15	0	3	3	29	5	3	15	73
DSS	5	7	1	2	5	5	0	2	27
AHP/ANP	8	0	1	2	5	6	0	2	24
DEA	14	0	3	3	2	***170***	1	2	***195***
Simulation	66	6	11	10	23	20	6	14	156
Regression	64	0	26	51	106	17	23	54	**341**
Logistic	25	0	9	25	27	1	5	5	97
Heuristics	3	48	0	1	6	0	0	0	58
Genetic Alg.	8	42	1	0	3	2	0	1	57
Big data	16	0	7	11	14	1	3	3	55
Info. Systems	30	0	4	14	12	5	6	7	78
Data mining	20	1	5	5	7	2	0	2	42
Total	**274**	104	71	127	239	***234***	47	107	**1203**

[a]Note that OR methods appear here in the topic (title, keyword, or abstract) of the articles, and HE and the area appear in the title of the articles, while in Table 1.3, the method appears in the title. The search was done in the WoS (assessed from the Web of Science during Aug. 2020). The bold figures indicate the maximal value of the columns' totals and the maximal value of the rows' totals. The bold italics figures indicate the largest number in the table (not including the the column and row of totals) and its row and column total

business. Moreover, DEA is composed of many linear programming (LP) problems, where LP is also a specific mathematical programming and optimization method—see the review by De la Torre et al. (2016) on the literature review of DEA in HE in the context of efficiency.

1.4 Issues in the HE Sector

This section presents examples of major issues in HE where OR methods can be applied.

1.4.1 Is HE a Product?

There is considerable debate in the HE literature about whether students are *customers* or *consumers*, or both, in their role as participants in higher education. Barrett (1996) published a warning on students as consumers, and Baldwin and James (2000) wrote about the concept of students as *informed customers*. Some use course descriptions in universities as "products" (Conway et al., 1994). Although others also argue that participation in higher education is not strictly a product and put forward a well-argued case for HE as a quasi-commercial service industry (Brookes, 2003). Passionate, articulate arguments were also put forward against the marketization of HE and business terminology, increasingly adopted and accepted by some educationalists. Those who oppose the emergence and imposition of the marketization of higher education argue strongly that *business values have no place in higher education*, because such values are ethically in conflict with educational values (Gibbs, 2018). Nevertheless, in 2006, Hemsley-Brown and Oplatka surveyed 63 articles on HE marketing, during 1992–2005, and again, in 2021 Oplatka and Hemsley-Brown (2021) reviewed 105 such articles, for the period 2005–2019, indicating that HE marketing has grown greatly. They report that their 2006 review was cited 1000 times (ibid.). Obviously by now, the use of marketing has become one of the main tools for recruiting students as part of globalization in HE.

At the turn of the millennium, it became evident that HE is an industry, and an important one (Goldin & Katz, 1999), with all the parameters of the industry: selling products (courses, degrees at various levels and in different professions, research, and knowledge), in large quantities (massification of HE), with import (globalization of HE) and export (international students), and marketing (e.g., advertisements and ranking). HE has a price (tuition), quality assurance (accreditation), research and development (R&D) contracts with industry, and entrepreneurial initiatives (see Sect. 1.4.2 below). The size of HE in the industry was estimated by Altbach et al. (2017) at about 200 million students in 22,000 HE Institutions (HEIs) worldwide. In many developed countries, over 50% of the 18–24 age group are students. The commodification of HE is *here*, and OR/MS methods are applicable, as shown in the previous sections.

1.4.2 University–Industry Relations

STEM (Science, Technology, Engineering, and Mathematics) graduates/students who acquired knowledge from HEIs are at the core of entrepreneurial successes in the industry. Universities and faculty have strong relations with industry R&D, in the form of knowledge transfer, patents, incubators, and industrial parks (Etzkowitz, 2001). Etzkowitz and others developed the “triple Helix interaction” of:

1. *University*, which creates basic knowledge
2. *Industry*, which produces commercial goods
3. *Government*, which regulates the markets, and provides some public infrastructure, and support.

Etzkowitz and Zhou (2018) present various models of cooperation between these three sectors—including evolving first, two out of three cooperation’s, and then cooperation of all three. They point at the two famous successful examples: Silicon Valley in California and the Boston area in the USA. Furthermore, often, cooperation of two of the three elements creates intermediary institutions, such as “science park” (ibid.). The European Union’s programs, such as, Horizon 2020, is another example that combines university-industry scientific cooperation across countries, see: https://ec.europa.eu/programmes/horizon2020/sites/horizon2020/files/H2020_inBrief_EN_FinalBAT.pdf

Tole and Czarnitzki (2010) were concerned that—commercializing science via academic spinoffs—may cause a “brain drain” from academia.

To estimate the use of OR methods in the context of industry, Table 1.2 shows the grouping of ten OR groups of methods and four groups of functional areas in HE. The *industry* group is composed of five specific areas, as shown in Appendix 3. The total number of articles of the *industry* group applied to HE is 12,072 (in column 3 of Table 1.2); this high number points at the centrality of the *industry* area in HE, in the last 20 years. However, as shown in Table 1.3, out of these 12,072 articles, the total number of articles with OR method in their title is only 172—a low number (only 1.425%).

Similarly, the *R&D* group of areas, as shown in Appendix 3, is composed of six specific areas: *transfer of knowledge*, *research and development*, *patents*, *industrial parks*, *incubators*, and *entrepreneurship*. The total number of articles of the R&D group in HE is 8136 (in column 3 of Table 1.2), this high number points at the centrality of R&D in HE, over the last 20 years. However, as shown in Table 1.3, the total number of articles with OR methods in the *R&D* group is only 72 articles out of the above, 8136 articles—a very low number (only 0.885%). Thus, there is a great potential for applying OR methods to the above six areas of *R&D* and *industry*.

1.4.3 Student Debt

Student debt is a major issue in the USA, to be resolved at the national and state levels. Many students are not able to repay their loans; one of the main factors is the decline in the income premium for graduates compared to non-graduates [see, for example, the documentary film *Ivory Tower* [https://en.wikipedia.org/wiki/Ivory_Tower_(2014_film) directed by Rossi, assessed on Sept. 2020]. Over 40 million borrowers in the US owe more than $1.5 trillion in loans. Krishnan and Wang (2019) show that student debt is *negatively related* to the propensity to start a firm, which affects the economy *negatively*; thus, the impact of student debt has additional ramifications. Although there are doubts, about the power of planning to resolve such issues (Thelin, 2018), we believe that without immediate and long-run planning, the problem may intensify.

1.4.4 Internationalization in HE

De Wit and Altbach (2020) review the development of *internationalization* in HE during the past 50 years—from a minor activity to a central strategically important issue in HE, worldwide. Internationalization fosters the global knowledge economy. Research intensive universities play a central role in internationalization—the exchange, import, and export of researchers, students, and knowledge. In ranking universities, internationalization is one of the central factors. Many universities even opened branches abroad, as a strategy. Online programs and courses such as MOOCs (massive open online courses) are available worldwide via advanced ICT (information and communication technology), which widen the boundaries of internationalization, and reduces its costs—the concept of internationalization at home is growing.

Interestingly, Altbach and de Wit (2018) questioned the continuation of internationalism in HE, due to issues of academic freedom, nationalist–populist arguments, ethics, the role of English, branch campuses, and anti-immigration (e.g., Brexit). Unfortunately, these predictions of the drastic reduction in internationalization materialized, completely from another reason—the COVID-19 pandemic, as they admit later (De Wit & Altbach, 2020).

As shown in Appendix 3 *internationalization* functional area in HE had 4253 articles during 2000–2019—the maximal number of articles in column (4). But in Table 1.4, out of 4253 articles, *internationalization* had only 106 papers with applications of OR methods (about half of them used regression model). Thus, there is a great potential for using OR methods for *internationalization* in HE.

1.4.5 EduTech and the Fourth Industrial Revolution

HE follows the development of technology, economy, political, and social processes. More specifically, the materialization of these processes is expressed in what we may call ***EduTech*** (educational technology), its expression is in: E-learning, MOOCs, ICT, educational simulators, simulations, multimedia, PowerPoint, computer educational games (e.g., business game), gamification, virtual library, virtual laboratory, web-based educational technologies, big data, analytics, etc. The term EduTech has been used mainly in the industry that produces technological educational tools. We use it in the context of these various tools and methods for HE in all academic disciplines and in the administration of HE (see also, Mosteanu, 2020). We predict that more and more HEIs will have to establish EduTech units to support faculty and students, in the use of all these technological methods, just like computer services today—some already exist, but not enough (especially for social sciences and humanities users).

Every industrial revolution (IR) has required more and more skilled manpower. Schwab and Davis (2018) discuss the fourth IR (also termed Industry 4.0) and its implication on the economy and society. (See Table 1.5, which summarizes the four IR eras in simple general terms, employing the main emerging technologies, along with new academic disciplines, in each IR era.) Gleason (2018) addresses the effect of the fourth IR on various aspects of HE: liberal arts, integration of STEM innovations, changing role of libraries in the digital age, global trends in youth

Table 1.5 Evolvement of the four Industrial Revolution (IR) and HE

Era[a]	Main emerging technologies	Main new academic discipline evolved
Pre IR (pre-1770)	Raw materials, man & animal power, wheels, tools	Humanities, Sciences, Civil Engineering, Medicine, Arts
First IR (1770–1880)	Machines, steam, waterpower, trains	Mechanical Engineering, Social Sciences
Second IR (1880–1940)	Electricity, radio, telephones, production lines, advanced materials	Electrical Engineering., Industrial[b] Engineering, Management[b], Material Engineering
Third IR (1940–1995)	Electronics, television, computers, information. Systems, spaceships, artificial intelligence	Nuclear Engineering, Aeronautical Engineering, Electronic Engineering, OR/MS[b], Computer Science
Fourth IR (1995+)	Smart robotics, biotechnology, cyber technology, cellular phones, the internet, ICT[c], big data	Robotics (Smart Sys.), Big Data Sustainable Environment, Analytics[b], **EduTech**[c]

[a]The exact years can never be accurate due to the overlap between eras; moreover, there are some variations among countries—the leading countries are North America and Europe
[b]Often OR/MS is part of Management or Industrial Engineering, even called Analytics
[c]EduTech is educational technology, the use of technology in teaching and learning

mobility, development of lifelong learning programs, E-learning, and working from home (also teaching and research).

Already, in 1997, Slaughter and Leslie (1997) wrote about *academic capitalism* and the entrepreneurial university—highlighting such issues as globalization, financial-driven academic policies, technology transfer strategies, and intellectual property (see Sect. 1.4.2 above). They claim that: "As the industrial revolution at the end of the nineteenth century created the wealth that provided the base for postsecondary education and attendant professionalization, so the globalization of the political economy at the end of the twentieth century is destabilizing patterns of university professional work developed over the past hundred years. Globalization is creating new structures, incentives, and rewards for some aspects of academic careers and is simultaneously instituting constraints and disincentives for other careers."

Etzkowitz (2001) wrote about the *second academic revolution* and the rise of entrepreneurial science, in which began: the entrepreneurial involvement of universities in industry, incubators, research parks, university spinouts, intellectual property, licensing strategies, and entrepreneurial faculty (see also Etzkowitz & Zhou, 2018). The third and fourth IR require workers with HE, which is the justification for the massification of HE, since the 1950s. This is the period when OR developed as an academic discipline—for improving civil organizations in business and industry and in public organizations, such as HE.

1.4.6 The Pandemic and EduTech

The years 2020–2021 will be remembered because of the COVID-19 pandemic, which shook up mankind's major systems: health, economy, education, transportation, culture, etc. HE was affected greatly, as campuses were closed to most frontal-teaching activities, and online teaching took over. In the beginning, HEIs created teaching guides and conducted online workshops to equip staff and students in the use of various online learning platforms, such as Zoom, Skype, Moodle, and Google Drive (Crawford et al., 2020). Teachers were trained online by information technology teams, who also provided support as needed. As shown in Table 1.6, in countries that reported campuses closed by the end of March 2020 (17 out of 20 countries), only three countries (including the USA) reported that only *some* campuses (not all) were closed. Only eight countries reported that *all* HEIs moved to online teaching, while the other 11 reported that *some* HEIs moved to online teaching, but not all (ibid.). While the long-run ramifications of the pandemic on HE delivery and organization are not yet clear, HE is currently in a new era of ICT dominance and at a faster pace than other systems. It appears that blended learning—defined as the combination of traditional face-to-face education and technology-mediated instruction (Porter et al., 2014) may be the future trend in HE. One of the potential negative impacts of the coronavirus on HE is on the mental

Table 1.6 Campus closures and the move to online teaching during COVID-19 pandemic in selected countries[a] by the end of March 2020

Type of Economy	Countries	Campus closure	Move to online
Developed	Australia, Germany, Italy, Ireland, United Kingdom	All	All
	United States of America	Some	Some
Developing	Brazil, Singapore	Some	Some
	China, Egypt, Hong Kong	All	All
	Chile, India, Indonesia, Jordan, Nigeria, South Korea, South Africa, United Arab Emirates	All	Some

[a]Based on Crawford et al. (2020)

health of students and academic staff, which may require special attention on the part of the administration (Sahu, 2020).

1.4.7 Planning in HE

Marshall (2018) wrote about using technology to catalyze change in university learning and teaching. Almog and Almog (2020) point at many wrongs in the university model and try to portray what will come in its place—new organization of the learning space and more: E-learning, MOOCs, badges, vendors, gaming in HE learning, networking, etc.

It seems that the COVID-19 pandemic is the crisis that is pushing all the above forecasts, of various researchers (Almog & Almog, 2020; Altbach & de Wit, 2018; Etzkowitz, 2001; Gleason, 2018; Marshall, 2018; Schwab & Davis, 2018; Slaughter & Leslie, 1997), into a variety of combinations of new directions, as shown in the limited survey, presented in Table 1.6. For example, internationalization declined, in the physical sense (traveling between countries), but ICT (such as Zoom) allowed more E-learning, which *increases* internationalization in the virtual sense. Teachers who refused to use E-learning in the past are forced to do it now—something that could happen only in a crisis. Working conditions have changed completely—flextime has changed to working from home, which may affect the future amount of office space required. In conclusion, planning is urgent—more than ever—in the short term and in the long term. OR models were born during crisis (World War II) and are urgently needed in the COVID-19 pandemic crisis—thereafter in general (i.e., unemployment, health) and in HE.

It seems that digital literacy and ICT will be crucial for the success of all participants in HE: lecturers, students, and administrators. For their survival, more and more HEIs will probably agree to give credit for external courses in the academic supermarkets that will be supplied by external providers. Special bodies will evaluate the quality rating of these academic products, and the reliability of student evaluation systems, grades, and the number of credits (Almog & Almog, 2020). The universities need to price partial tuition for those who purchase courses elsewhere. It is not clear whether the overall tuition for a degree will drop in price. Students may prefer to attend universities that give them credit for previous courses and attractively reduced tuition fees. The universities, for their part, may gain a reduced dropout rate—as they will accept students with some academic background from online courses. Moreover, universities may offer (sell) online or MOOCs (Wong et al., 2019) in the virtual *academic supermarket* to gain visibility. To motivate teachers to develop good products, incentives can be developed, like e-book royalty payments (per student). In a successful situation, all may gain: reduce tuition, dropout rate will be reduced, and student satisfaction will increase. See further on blended learning in Porter et al. (2014).

1.5 Summary and Conclusions

This chapter provides an overview of the use of OR methods and functional areas in HE. A search in 40 OR journals revealed that HE (or its synonyms) appears in the title of only 0.3% of their articles, from 1950–2019; this is an astonishing low rate, compared to other fields (e.g., health). Moreover, in 17 of the journals, no article was found with HE in its title. In a web of science search, out of 58 OR methods listed in our study, the 11 leading methods (in number of articles) are: *simulation, regression* (including *logistics*), *analytics, information systems, data mining, big data, AHP, forecasting, DEA, and DSS*. The Pareto 20/80 rule holds here—as less than 20% of the methods comprise about 80% of the articles. Similarly, overall, from 30 functional areas, we identified eight leading areas in HE: *strategy, internationalization, efficiency, network, industry, entrepreneurship, marketing*, and *finance*. Looking at methods by functional area, *DEA* by *efficiency* is the leader.

In summary, there is great potential for academics in OR to utilize OR models to improve their own HE institutions in all functional areas. The main problems of applying OR methods in HE (in other systems too) is the lack of unified information systems at all levels of HE. Getting the data takes up most of the time and cost of the application of OR methods. Indeed, one of the leading methods in our analysis of OR methods in HE is *information systems*.

OR was born at a time of crisis, like the COVID-19 pandemic today, calling OR specialists to take the lead once again in using the widened arsenal of OR methods to save the HE system. HE had been in trouble during the last decade, even in the leading country in HE—the US (see Merigo & Yang, 2017)—addressing problems such as student debt in the US and EduTech. As Thelin (2018) claims, American HE needs a substantive "New Deal" in purposes and policies.

For future research, various combinations of OR methods have great potential. Mingers and Gill (1997) foster combining management science methodologies. Along these lines, Sinuany-Stern et al. (1994) used DEA with some statistical methods to measure the efficiency of academic departments at a university. Cooper (1999) suggested to combine DEA with commonly used statistical methods—new and old—to further enhance the scope of OR. One of the leading OR methods is *data mining*, which combines statistical models, such as clustering, regression, and decision-making—see reviews on educational data mining by Aldowah et al. (2019) and by Romero and Ventura (2020).

Another direction, for future research, is to extend the search method of articles on OR in HE and their areas of application (in Appendix 2 and 3), such as 1. Additional OR methods (e.g., *optimal control* and *fuzzy logic/set*) 2. Additional functional areas (e.g., *enrollment* and *faculty/lecturer*); 2. Extending the search from the WoS to Google Scholar or other sources; 3. To perform a study among HEIs' administrators on the specific OR methods they actually use and their area of application within HE.

Appendix 1: The number of articles published in 40 OR journals with HE in their title during 1980–2019

Journal title	Year journal opened	Number of articles published in 1980–2019[a]			Number of articles published in 2000–2019[a]		
		Total number	HE[b] number	HE %	Total number	HE[b] number	HE %
Journal of the Operational Research Society[a]	1950	8449	58	0.686	3827	20	0.522
Journal of Optimization Theory and Applications	1967	5873	0	0	3346	0	0
Management Science	1954	5817	23	0.395	3306	18	0.544
Operations Research	1952	3842	6	0.156	1933	2	0.103
Transportation Science	1969	1594	0	0	943	0	0
International Journal of Systems Science	1970	6459	1	0.015	3362	0	0
INFOR	1963	973	19	1.952	459	9	1.960
Mathematical Programming	1971	3571	0	0	1964	0	0
Networks	1971	1969	2	0.101	1119	1	0.089
Omega	1973	2949	17	0.576	1603	13	0.810
Computers and Operations Research	1974	5496	15	0.272	4172	5	0.119
Mathematics of Operations Research	1976	2112	0	0	1062	0	0
European Journal of Operational Research	1977	***18,412***	49	0.266	***11,916***	30	0.251
RAIRO–Operations Research	1977	689	0	0	689	0	0
Transportation Research Part B–Methodological	1979	2754	1	0.036	2035	0	0
OR Spectrum	1979	661	3	0.453	661	3	0.453
Optimal Control Applications and Methods	1980	1394	1	0.071	850	0	0
Interfaces	1983	3712	***76***	***2.047***	1513	***41***	***2.709***
Annals of Operations Research	1984	4571	11	0.240	3783	11	0.290
Applied Stochastic Models in Business and Industry	1985	1122	1	0.089	1078	1	0.092
Decision Support Systems	1985	3073	14	0.455	2525	12	0.475

(continued)

Optimization	1985	1970	0	0	1685	0	0
Queueing Systems	1986	1324	0	0	1008	0	0
Asia-Pacific Journal of Operational Research	1987	1052	2	0.190	837	1	0.119
Expert Systems with Applications	1990	12, 552	37	0.294	11, 844	28	0.236
Discrete Event Dynamic Systems Theory and Applications	1991	494	0	0	410	0	0
Journal of Global Optimization	1991	2684	0	0	2357	0	0
Computational Optimization and Applications	1992	1597	2	0.125	1476	2	0.135
TOP	1993	544	0	0	544	0	0
International Transactions in Operational Research	1994	711	2	0.281	711	2	0.281
INFORMS Journal on Computing	1996	947	2	0.211	916	2	0.218
Journal of the Operations Research Society of Japan	1996	849	1	0.117	289	1	0.346
Mathematical Methods of Operations Research	1996	1169	0	0	1008	0	0
Journal of Scheduling	1998	781	6	0.768	781	6	0.768
Fuzzy Optimization and Decision-Making	2002	313	0	0	313	0	0
SORT	2003	215	1	0.465	215	1	0.465
Discrete Optimization	2004	498	0	0	498	0	0
Central European Journal of Operations Research	2006	576	1	0.173	576	1	0.173
European Journal of Industrial Engineering	2008	401	1	0.249	401	1	0.249
Pacific Journal of Optimization	2008	529	0	0	529	0	0
Total		**114, 698**	**352**	**0.306**	**78, 544**	**211**	**0.268**

[a]formerly Quarterly Journal of Operational Research
[b]Assessed from the WoS on July 2020; HE synonyms used were: higher education, academic, college, university, and tertiary education. The bold italics figures are the maximal values of each column. The bold figures in the last row indicates the total of each column

Appendix 2: The number of articles published in WoS Journals with HE and OR method[a] 2000–2019

Method	Method in topic (1)	Method in topic and HE in title (2)	Method in title and HE in topic (3)	Method and HE in title (4)	Percent of column (4) from column (1)
1. Operations research					
Operations research/Operational research	8013	81	94	20	0.250
Management science	1865	57	51	9	0.483
Scientific management	1146	79	14	10	***0.873***
Operations management	4448	56	93	16	0.360
Analytic/Analytics	188, 877	1355	1538	352	0.186
Quantitative model/methods	15, 134	178	48	10	0.066
System analysis/Systems analysis	16, 589	78	103	18	0.109
2. Decision analysis					
Decision science/Decision analysis/Decision theory	16, 969	58	94	13	0.077
Decision support/DSS	67, 361	315	630	103	0.153
Multi-criteria decision	9631	62	58	9	0.093
Analytic hierarchy process/AHP/ANP	31, 930	404	428	156	0.489
PROMETHEE	1431	8	13	5	0.349
Decision tree	22, 914	134	160	32	0.140
3. Mathematical programming					
Mathematical program-ming/Optimization	10, 604	16	28	1	0.009
Linear programming/LP	66, 016	75	100	13	0.020
Chance constraint	576	0	0	0	0.000

(continued)

(continued)

Method	Method in topic (1)	Method in topic and HE in title (2)	Method in title and HE in topic (3)	Method and HE in title (4)	Percent of column (4) from column (1)
Data envelopment analysis/DEA	20, 128	318	351	159	***0.790***
Goal Programming/Goal Program	2684	19	34	8	0.298
Soft constraint/Soft constraints	1312	56	4	3	0.229
Nonlinear programming/NLP	16, 951	23	41	4	0.024
Quadratic	115, 781	65	122	4	0.003
Separable	25, 466	12	29	0	0.000
Game theory	23, 520	72	82	27	0.115
4. Discrete Optimization					
Discrete optimization	2464	5	3	1	0.041
Integer programming	15, 477	53	47	18	0.116
Mix integer/MIP	20, 781	8	25	0	0.000
5. Stochastic					
Stochastic	243, 606	119	464	21	0.009
Markov	115, 921	52	220	14	0.012
Queue/queuing	41, 925	41	89	11	0.026
Dynamic programming	22, 997	7	34	2	0.009
6. Forecasting					
Forecasting	150, 520	328	1146	81	0.054
Time series	161, 508	178	473	30	0.019
Moving average	14, 266	8	18	0	0.000
Exponential smoothing	1709	5	7	1	0.059
7. Simulation					
Simulation	***2,269,462***	1632	***6655***	***465***	0.020
Industrial dynamic/dynamics	329	2	1	0	0.000
Monte Carlo	225, 155	101	336	18	0.008
Discrete events	13, 894	20	80	4	0.029
Agent based/ABS	47, 056	97	297	38	0.081

(continued)

(continued)

Method	Method in topic (1)	Method in topic and HE in title (2)	Method in title and HE in topic (3)	Method and HE in title (4)	Percent of column (4) from column (1)
8. Multivariate statistics					
Multivariate statistics	4049	12	7	1	0.025
Regression	916, 392	***8088***	983	137	0.015
Logistics	300, 691	2972	240	37	0.012
Principle component/PCA	79, 897	105	60	9	0
Canonical correlation	5491	50	20	6	0.109
Discriminant analysis	34, 213	88	51	8	0.023
9. Heuristics					
Heuristics	111, 764	299	371	50	0.045
Greedy	22, 354	14	35	5	0.022
Metaheuristics	5877	28	20	3	0.051
Tabu Search	8586	31	32	3	0.035
Simulated annealing	19, 441	31	58	6	0.031
Genetic Algorithms	109, 446	125	313	39	0.036
10. Expert systems					
Expert system/Expert systems	15, 517	76	129	18	0.116
Machine learning	112, 381	207	528	37	0.033
Data science	3528	45	98	15	0.425
Data mining	66, 293	606	761	4	0.006
Big data	47, 119	481	901	283	0.601
Information systems/ Information management	73, 957	1177	1105	284	0.384
Computational intelligence	5356	9	31	6	0.112
Total	**5, 958, 768**	**20, 621**	**19, 753**	**2627**	**0.044**

[a]Assessed from the WoS on August 2020; HE synonyms used were: higher education, academic, college, university, and tertiary education. The bold italics figures are the maximal values of each column. The bold figures in the last row indicates the total of each column

Appendix 3: The number of articles published in WoS journals with HE and functional area[a] during 2000–2019

Functional area	Area in topic (1)	Area in topic & HE in title (2)	Area in title & HE in topic (3)	Area & HE in title (4)	Percent of column (4) from column (1)
1. Transportation					
Transportation	144, 001	474	587	98	0.068
Transshipment	1426	1	1	0	0
Assignment	139, 140	1343	666	124	0.089
Project management/CPM/Gant/PERT	24, 381	327	450	97	0.398
Network/Networks	2, 395, 625	8865	11, 883	2582	0.108
Location	781, 639	2159	1312	147	0.019
Scheduling	266, 136	1443	1120	78	0.029
Timetabling	1609	240	358	186	***11.560***
2. Industry					
Industry	641, 524	6500	6169	2474	0.386
Logistics	41, 095	315	603	112	0.273
Maintenance	361, 693	1143	1075	146	0.040
Reliability	489, 641	3110	2753	300	0.061
Inventory	166, 842	2867	1472	325	0.195
3. **R&D**					
Transfer of Knowledge/Knowledge management/Management of knowledge	27, 078	851	1073	387	1.429
R&D/Research and development	91, 236	1567	1107	324	0.355
Patent/Patents	63, 285	1080	1087	267	0.422
Industrial park/Industrial parks	2157	12	20	3	0.139
Incubator/Incubators	6717	274	209	79	1.176
Entrepreneurship/Entrepreneurial	48, 601	3648	4640	2255	4.640
4. Bussiness/management					
Marketing	626, 982	6226	5345	1339	0.214
Finance/Financial	318, 978	5048	3505	1146	0.359
Strategy	1, 880, 330	***16,261***	***12,151***	1261	0.067
Balanced scorecard/BSC	6976	189	160	70	1.003

(continued)

(continued)

Functional area	Area in topic (1)	Area in topic & HE in title (2)	Area in title & HE in topic (3)	Area & HE in title (4)	Percent of column (4) from column (1)
Efficiency/Efficient	***2,643,368***	5862	4644	804	0.030
Accounting	1, 196, 791	6642	2388	655	0.055
Investment	206, 858	1698	1057	216	0.104
Revenue management	2087	6	31	4	0.192
Policy modeling/policy model/Policy models	2619	11	6	2	0.076
Renovation	8184	176	116	57	0.696
International/ Internationalization	706, 035	10, 539	11, 201	***4253***	0.602
Total	**13, 293, 034**	**88, 877**	**77, 189**	**19, 791**	0

[a]Assessed from the WoS in August 2020. HE synonyms used were: higher education, academic, college, university, and tertiary education. The bold italics figures are the maximal values of each column. The bold figures in the last row indicates the total of each column

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Chapter 2
A Systematic and Updated Review of the Literature on Higher Education Marketing 2005–2019

Izhar Oplatka and Jane Hemsley-Brown

Abstract The purpose of this review is to identify key research themes in the field of higher education (HE) supply-side marketing through a systematic search of journal article databases of papers published between 2005 and 2019, to report on current issues and themes, and ascertain research gaps in the literature for exploitation in future research. Based on an analysis of 105 papers from the field of HE marketing, five major themes characterizing the research on HE marketing are presented in the paper: the marketization of HE; marketing communications; branding, image, and reputation; marketing strategy; and recruitment, alumni and gift-giving. Some thoughts about the nature of the knowledgebase in this field and recommended topics for research conclude the paper. Note, 46 papers were based on quantitative methodologies (constitutes 43.8% of the reviewed papers).

Keywords Educational Marketing · Branding · Higher Education · International Marketing · Advertising · Institutional Image

2.1 Introduction

In 2006, the current authors published a systematic review of journal papers in the area of HE marketing (Hemsley-Brown & Oplatka, 2006) covering 1992–2004, and since publication, this article has been cited in almost a thousand works (949 citations on (Google Scholar, 2019)). Since 2004, however, research on HE marketing has increased dramatically due to a paradigm shift toward the increasing marketization of HE worldwide, which inevitably generates considerable research

I. Oplatka (✉)
School of Education, Tel Aviv University, Tel Aviv, Israel
e-mail: oplatka@tauex.tau.ac.il

J. Hemsley-Brown
Surrey Business School, University of Surrey, Guildford, UK

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in all fields related to HE markets marketing, marketization, and choice (Hemsley-Brown & Oplatka, 2015a); this is also clear from the findings of the current review.

Authors have provided a range of rationales for research in this field, including (see Hemsley-Brown & Oplatka, 2015a): increasing globalization (Maringe, 2010); internationalization and the need for international marketing (Chen, 2008); increasing international student mobility (Wilkins & Huisman, 2011); expansion in student demand (Leslie, 2003); increasing access to information (Veloutsou et al., 2005); changes in fees and funding (Abu Bakar & Abdu Talib, 2013) changing demographics (Bornholt et al., 2004) and concerns about the fundamental transformation of education itself (Gibbs, 2007a)

Therefore, it is unsurprising that together with increasing competition nationally and internationally for home and overseas students and reduced public funding HEIs are now all too aware of the need to be more sophisticated and professional in their marketing (Favaloro, 2015; Hemsley-Brown & Oplatka, 2006). The objectives of this chapter, therefore, are to return to the literature to conduct an update of the 2006 (Hemsley-Brown & Oplatka, 2006) review; to document the search process; identify relevant papers in line with the previous search parameters; draw up revised research themes, document the findings; and make recommendations for future research in the field.

2.2 Key Issues from the 2006 Literature Review

In our 2006 paper, we commented that higher education marketing tended to rely on marketing approaches in use in the business sector in the absence of specific HEI marketing techniques and methods (Hemsley-Brown & Oplatka, 2006), although concerns have often been raised about the relevance of ideas imported from the for profit sector (Gibbs, 2001; Gibbs, 2007a). Before 2006 it was clear that books and manuals available for marketers in HE were based on business marketing models—many focusing on a "how-to" approach. In particular, a leading text in higher education marketing was Kotler and Fox (1985) *Strategic Marketing for Educational Institutions*, re-printed in 1995. The research agenda in 2019 has widened, and the need for "how-to-do" books has seen little expansion, with the exception of two HE marketing specific texts: *Marketing Higher Education: Theory & Practice*; and *Marketing Further & Higher Education: an educator's guide to promoting courses, departments and institutions* (Gibbs & Knapp, 2012; Maringe & Gibbs, 2008).

In the 2006 paper, the authors highlighted the tendency of authors to also rely on business marketing texts to provide definitions of the concepts covered in research articles, particularly where current or existing theory is utilized for empirical research. The authors commented that in particular texts by Kotler (e.g., Kotler & Armstrong, 2003; Kotler & Fox, 1985) were frequently cited, and several articles were named in this regard (Ivy, 2001; Nguyen & LeBlanc, 2001; Klassen, 2002; Maringe & Foskett, 2002; Binsardi & Ekwulugo, 2003; cited by Hemsley-Brown & Oplatka, 2006).

Findings from our 2006 review also revealed that there was considerable debate in journal articles about students as customers and whether students were consumers, customers, or both in their role as participants in higher education. Authors also reported opposition to the notion of a student as a consumer (Baldwin & James, 2000; Barrett, 1996) and to the description of courses in universities as "products" (Conway et al., 1994), although authors also argued that participation in higher education is not strictly a product and put forward a well-argued case for HE as a service (e.g., Brookes, 2003; Mazzarol, 1998; Nicholls et al., 1995). Passionate, articulate arguments were also put forward against the marketization of HE and the adoption of business terminology (Hemsley-Brown, 2011), increasingly adopted and accepted by some educationalists. Those who oppose the emergence and imposition of the market in higher education argued strongly that business values have no place in higher education because such values are morally and ethically in conflict with educational values (Gibbs, 2002; Gibbs, 2007b).

The following sections in this chapter focus on an update of the 2006 review and present the thematic findings of our systematic literature review of HE marketing for the period 2005 (the end date used for the 2006 review) to 2018. The purpose of this review is to identify key research themes in the field of higher education (HE) supply-side marketing through a systematic search of journal article databases of papers published between 2005 and 2019; to report on current issues and ascertain research gaps in the literature for exploitation in future research. The following section sets out the methodology for the review and is followed by the findings, with subsections based on the themes which emerged from the analysis: the marketization of HE; marketing communications; branding, image and reputation; marketing strategy including relationship marketing; and recruitment, alumni and gift-giving.

2.3 Methodology

A previous review paper on higher education marketing by the current authors applied a systematic review approach suggested by Booth (2001) and focused on presenting the "best evidence" (Hemsley-Brown & Oplatka, 2006). The main principles of this approach have been adopted for this review by searching named databases, systematically recording the hits, and downloading papers relevant for the review based on previously identified search criteria. The current searches were based on updating our previous systematic review (with papers published between 1992 & 2004); therefore, the current review is based on searching within the period 2005 to 2018; the search terms matched to the themes which were reported in the original review and extended where new topics emerged following the re-categorization of selected papers (e.g., the inclusion of "social media," "marketing strategy and "alumni").

For the updated literature review, the authors of the current research conducted systematic, documented, and extensive searches of academic databases, namely British Education Index; ERIC; Emerald Full Text; EBSCO (Business Source Complete; & PSYCINFO and Psych Articles). Specific internet searches using Google Scholar were carried out the follow up secondary references, to access some academic articles in the full text more directly and to identify further articles related and relevant to the focus of the review. Searches were initially very open with no limits (with the exception of dates (2005-2018) and "scholarly" articles. However, due to the high number of hits (93,996 hits for EBSCO business source complete search using "marketing" and "university" or "higher education"), and the large number of irrelevant articles included, the search terms were de-limited as follows "marketing" + "university" or "higher education," not teaching/learning/instruction—the latter phrase was used to exclude the high number of papers on pedagogy. In addition, the search parameters included specific databases (see above), "English language," and either "abstract" or "subject terms" (requiring separate searches). The purpose of the approach to searching and identifying articles was first, to ensure that as many articles as possible within the search parameters were identified, second to focus on the study's objectives, and third, to provide a search approach that excluded a large number of articles which were outside the parameters.

The review parameters filtered "hits" to focus on articles published in the English language but from anywhere in the world; scholarly journal papers were prioritized; opinion pieces and conference papers were excluded either during the searching or after the initial sort process; searches used both abstract and subject terms for searching. Following pre-reading or visual scanning of all papers, and some deselection, 165 papers (empirical and conceptual) from 2609 hits, were downloaded for further scrutiny. Reference manager version 12 software (with links to original sources) was used to capture and track the papers for further assessment. After reading each paper to determine the focus and objectives, 60 papers were excluded from the original selection of 165. Reasons for deselection were based on lack of relevance to the study; research sample was a single institution—frequently from a single discipline; papers were short opinion pieces; or papers related to sectors other than higher education. This resulted in a final total of 105 papers for the review.

In our 2006 paper, the authors used "thematic analysis" and summarized the findings based on various relevant themes (Tranfield et al., 2003) which emerged from analysis of the selected papers. For the earlier paper the authors curated a small selection of papers, resulting in a final selection of 15 papers, which were considered the "best evidence" for each of the identified themes (based on objectives, design of the study, sample size, methodology, and rigor) and restricted the final selection to empirical papers. For the current review, the authors approached the task in a more traditional review style, and therefore did not curate the selection to only "best evidence," or to empirical papers only, but included all papers meeting the objectives and defined parameters. The authors conducted searches using the original thematic categorization from the 2006 paper and later added sub-headings or changed headings where appropriate to extend or to divide the thematic sections.

These sections (original themes are marked with *) are marketization, *marketing communications (with the addition of advertising and social media marketing), *image and reputation (with the addition of branding), application of *marketing models, and *strategic marketing were replaced by marketing strategy, which in the updated review includes *segmentation, targeting and *positioning, and *relationship marketing; *widening participation is now excluded, due to lack of relevant papers (related to HE marketing) since 2005; a new section on marketization is included in this review, and a small number of papers on recruitment and alumni are also new, based only on articles which relate to HE marketing (rather than to student choice which is reviewed elsewhere (Hemsley-Brown & Oplatka, 2015b). Table 2.1 provides a summary of topics with relevant sources and shows the number of papers included in this review.

The presentation of the findings section is structured as follows: first papers on marketing communications are analyzed, with subsections on advertising and a new topic, social media marketing. This is followed by a section covering marketing strategy, which includes subsections on segmentation, targeting and positioning, and relationship marketing. A substantial section follows on branding, which was not included in the previous review, with a subsection on image and reputation—which provides an update on research articles since our previous paper. A substantial section on marketization in higher education follows, and is a new topic that has emerged since 2005; finally, a short section on recruitment marketing and alumni, including gift-giving completes the review section of this review. A discussion and conclusion follow which highlight the themes which emerge from the review and suggest possible ways forward for researchers in the HE marketing field.

2.4 Findings

The inductive analysis of the reviewed papers yielded five major themes—marketization of HE, marketing communications, branding, marketing strategy, and relationship marketing, with sub-themes (see summary in Table 2.1). See Appendix for a list of all the articles included in the study, listed under headings by theme.

2.4.1 The Marketization of Higher Education

The searches, after applying the strict selection criteria, resulted in 17 papers on the marketization of higher education being selected for the review: 14 conceptual papers and three empirical papers (i.e., Bowl, 2018; Cardoso et al., 2011; Symes & Drew, 2017) (see Appendix 1). Marketization as a topic of research in higher education marketing emerged from this study as second in frequency after higher education branding. Marketization is defined as follows:

Table 2.1 Sources for higher education marketing literature review shown by subject focus

Main subject focus	Number of papers	Authors
Marketization	17	Gibbs, 2007; Brown, 2008; Mause, 2009; Molesworth et al., 2009; Newman & Jahdi, 2009; Miller & Brian, 2010; Weymans & Wim, 2010; Cardoso et al., 2011; Hemsley-Brown, 2011; Lowrie & Hemsley-Brown, 2011; Susanti & Dewi, 2011; Craven & Anne, 2012; Natale & Doran, 2012; Favaloro, 2015; Symes & Drew, 2017; Bowl, 2018; Gibbs, 2018.
Marketing communications	9	Adams & Eveland, 2007; Bonnema & Van der Waldt, 2008; Edmiston-Strasser, 2009; Schüller & Chalupský, 2011; Popović, 2015; Vuori, 2015; Gribanova, 2016; Royo-Vela, 2016; Pizarro Milian & Davidson, 2018.
• *Advertising*	3	Clayton et al., 2012; Papadimitriou & Ramírez, 2015; Jan & Ammari, 2016.
• *Social media marketing*	8	Zailskaite-Jakste & Kuvykaite, 2012; Palmer, 2013; Bélanger et al., 2014; Linvill et al., 2015; Brendzel-Skowera & Lukasik, 2016; Brech et al., 2017; Clark et al., 2017; Peruta & Shields, 2017.
Branding	23	Baker et al., 2005; Judson et al., 2006; Temple, 2006; Chapleo, 2007; Hemsley-Brown & Goonawardana, 2007; Judson et al., 2009; Chapleo, 2011; Furey et al., 2014; Aula & Tienari, 2015; de Heer & Tandoh-Offin, 2015; Delmestri et al., 2015; Holmberg & Stannegård, 2015; Kosmützky & Krücken, 2015; Satavøen, 2015; Chapleo, 2015a; Chapleo, 2015b; Fay & Zavattaro, 2016; Rooksby & Collins, 2016; Lee et al., 2017; Rose et al., 2017; Rutter et al., 2017; Winter & Thompson-Whiteside, 2017; Lomer et al., 2018.
• *Image and reputation*	13	Wolverton, 2006; Brown & Mazzarol, 2009; Angulo-Ruiz & Pergelova, 2013; Finch et al., 2013; Steiner et al., 2013; Idris & Whitfield, 2014; Tolbert, 2014; Drori et al., 2016; Plungpongpan et al., 2016; Chen, 2016; Saleem et al., 2017; Huisman & Mampaey, 2018; Lee & Chen, 2018.
Marketing strategy	5	Naidoo & Wu, 2011; Schofield et al., 2013; Alhakimi & Qasem, 2014; Nkala et al., 2014; Mogaji, 2016.
• *Market orientation*	6	Paviĉić et al., 2009; Camelia & Marius, 2013; Ross et al., 2013; Tayar & Jack, 2013; Alnawas & Phillips, 2014; Baber & Upadhyay, 2015.
• *Segmentation, targeting, and positioning*	4	Ghosh et al., 2008; Mazzarol & Soutar, 2008; Durkin et al., 2014; McAlexander et al., 2016
• *Marketing mix*	3	Enache, 2011; Moogan, 2011; Artur, 2015.
• *Relationship marketing*	5	Kim et al., 2010; de Macedo Bergamo et al., 2012; Purgailis & Zaksa, 2012; Iskhakova et al., 2017; Schlesinger et al., 2017.
Recruitment, alumni and gift-giving	9	Frølich et al., 2009; Pippert et al., 2013; Hulme et al., 2014; Stephenson & Bell, 2014; Alnawas & Phillips, 2015; Asaad et al., 2015; Stephenson & Yerger, 2015; Onk & Joseph, 2017; Pedro et al., 2018.
Total	105	

Source: The authors

> “Marketization in higher education refers to the adoption of free market practices in running universities. These include the business practices of cutting production costs, abandoning courses and programs not in demand, offering more popular programs and facilities and advertising to increase brand image, sales and the profit margins” (Hemsley-Brown, 2011) p118

The process of marketization in HE that began in the 1990s in many Anglo-American countries continues to receive attention in the second decade of the twenty-first century. Two papers succinctly clarified the challenges of the phenomenon in the context of higher education. Lowrie and Hemsley-Brown (2011) set out the differences between marketization and marketing and highlight the increase in the complexity of HE; the expansion of a consumerist dialog; the increasing focus on university rankings, and the importance of image, identity, and brand. Similarly, Miller and Brian (2010) analyze definitions of the commodification of HE and conclude that the commodification of this sector is already well established but outcomes based on values, principles, and liberalism are on the decline in favor of credentials, skills, and financial gain.

Three papers focus on HEIs’ responses to marketization, examining how universities in New Zealand and the UK balance the need to maintain a successful global brand (e.g., elitism) with national expectations (e.g., equality and fair access) (Bowl, 2018); and whether the political change in public and private universities and polytechnics in Portugal is transforming students into consumers (Cardoso et al., 2011). Similarly, Favaloro (2015) examined growth in student numbers and marketing investment patterns in Australian universities. They concluded that marketization brought about increased attention to performance, aggressive and intrusive announcements, and intensive competition between non-prestige universities and non-university providers.

As far as the outcomes of HE marketization are concerned, four conceptual papers (i.e., Brown, 2008; Craven & Anne, 2012; Newman & Jahdi, 2009; Susanti & Dewi, 2011) explored the implications, benefits, and limitations of the marketization of HE in general (Brown, 2008); marketization in respect to a particular social and educational aspect, such as social justice and unfairness of markets for students from lower-socio-economic groups (Craven & Anne, 2012); the impact of marketing on staff (Newman & Jahdi, 2009); and new regulations in Indonesia (Susanti & Dewi, 2011) who claim that marketization contributes to polarization particularly in terms of social class, poses barriers to access to HE for disadvantaged groups of students and fails to address educational inequity.

Finally, in this section, eight papers put forward a critical argument and conceptual debate in terms of a marketized HE system and the increasing marketization of HE—predominantly raising a raft of concerns regarding the operation of a free market in HE. Scholars set out an argument against advertising as part of the marketing of HE claiming that it intends to convince rather than inform prospective students (Gibbs, 2007b). Gibbs (2018) further argues against consumerism, claiming that it changes learners into customers who simply aim to gain a degree as if it was a mere commodity and transforms tutors into service providers. Authors also argue that by engaging with market discourse which is a neoliberalist construction (Symes &

Drew, 2017), universities are participating in the selling of HE experience as an economic asset. Hemsley-Brown (2011) examined the potential damage the market can inflict on HE and raises concerns that the core values of HE are in conflict with the market: free markets are known to exacerbate inequalities, she argues, and intervention is needed by governments to reduce this inevitable unfairness; Mause (2009) highlights the lack of progress by economists in identifying and measuring the harmful and beneficial effects of market signaling in the HE context; and Natale and Doran (2012) claim that academic freedom is considered less important than accountability and trust less important than utility in the market-like environment. Papers further warn against a decline in creativity and professional judgment following the marketization of HE (Weymans & Wim, 2010) and the shift in higher education towards a commodity that can be bought, rather than as a transformational experience (Molesworth et al., 2009).

2.4.2 Marketing Communications

The topic of marketing communications includes, according to Gribanova (2016), advertising, public relations (PR), direct marketing communications; personal selling; and sales promotion, both in an online and offline environment. Nine papers focused on marketing communication in their attempt to expose the problems of different types of communication, organizational factors, and outcomes in a higher education context (see Appendix 2). Authors from Serbia probed the types of marketing communications used by 131 HEIs (Popović, 2015) and found that they lacked integration. This problem could be related to institutional leadership, since Edmiston-Strasser (2009) identified the link between integration and leadership in research with a sample of 42 US universities. Similarly, (Schüller & Chalupský, 2011) explored types of problems for university marketing communications and examined how these communications are organized. Based on interviews with 20 marketing managers from the Czech Republic, they identified management structure problems in the universities, including faculty relationships, and suggested that faculties should have more responsibility for marketing communications within their faculties.

Further papers extended the concept of marketing communication and explored the connection with the institutional image. Thus, based on large-scale survey of students, researchers aimed to determine whether marketing messages need to be different for each market segment, and examined the content of symbolic images in promotional materials in different types of HE institutions (Bonnema & Van der Waldt, 2008). Research seeking to identify how universities can develop to improve their image by using social media tools found that advertising, word-of-mouth, content, and information about HEIs are the main influences on decisions in Spanish universities (Royo-Vela, 2016). While researchers studying public universities in Canada found that they tend to emphasize research achievements and rankings (Pizarro Milian & Davidson, 2018).

Finally, three papers explored marketing communications in the virtual world. Accordingly, Gribanova (2016) wrote a theoretical paper about developments in mobile marketing communications technology tools and the benefits to universities in engaging with these methods to communicate with students and prospective students. From a different viewpoint, research (Vuori, 2015) explored how 68 HEIs in Finland convey market differentiation on webpages targeted at prospective students and found that the websites emphasized the relevance of programs for employability and career prospects in addition to an international experience and context. Similarly, websites were used to divide institutions into three groups: accredited residential, regionally accredited online, and non-accredited online in a study of 150 universities in the USA (Adams & Eveland, 2007). Two further aspects of marketing communications justify further discussion, based on advertising and social media marketing.

Despite the apparent popularity of marketing communications as a topic for research, there is an overlap with social media marketing and website postings and website content.

2.4.2.1 Advertising

Advertising is a paid form of mass communication by an advertiser or company to specific readers, viewers, or the wider audience to achieve the specific goals (Kotler & Armstrong, 2003). Two papers explored marketing messages in the advertising campaigns of institutional communications and found striking similarities across institutions. In the first paper, the authors reveal five themes that 115 American HEIs use in messaging and advertising specific to institution communication: campus characteristics, academics, co-curricular activities, prestige building, and mission/purpose (Clayton et al., 2012). These authors argue that institutions are not creating unique messages; there is a great deal of similarity among them. The second paper reveals that the most salient content of advertisement campaigns in five US cities show similarities, despite the wide variation in types of institution. Similarities in the content of communication campaigns are based on students; logos; global scope, open campus, and careers (Papadimitriou & Ramírez, 2015).

In contrast, based on a survey with 350 prospective Malaysian students, Jan and Ammari (2016) examined the impact of online advertising on prospective students' decision marking and found that while online advertising is important in the student decision-making process, intrusive or intensive advertisements and campaigns have a negative impact on students' positive attitude and selection of a university.

The topic of advertising specifically remains relatively limited as a research focus, similar to the conclusions provided in the 2006 paper. We might speculate that the expansion of social media marketing is likely to have contributed somewhat to the lack of focus in research on a more traditional approach such as advertising and that advertising research is combined with other methods such as websites and social media messages.

2.4.2.2 Social Media Marketing

Social media marketing (SMM) utilizes the Internet and in particular social networking websites for communication and marketing purposes (Brech et al., 2017). Social media marketing has become a popular subject for research in HE marketing since the publication of our 2006 paper. This is a form of Internet marketing that utilizes social networking websites as a marketing tool for communication (Brech et al., 2017). Eight papers focused on social media marketing from multiple theoretical stances (Bélanger et al., 2014; Brech et al., 2017; Brendzel-Skowera & Lukasik, 2016; Clarke, 2007; Linvill et al., 2015; Palmer, 2013; Peruta & Shields, 2017; Zailskaite-Jakste & Kuvykaite, 2012); four of the papers focused on social media in general. First, authors develop a theoretical model to explain engagement with social media marketing and the outcome factors (Brech et al., 2017); second, the research identifies how universal the use of social media sites is for Polish universities (Brendzel-Skowera & Lukasik, 2016); a third, examined whether social media engagement impacts on relationship quality in respect of American universities and students (Clark et al., 2017); and finally researchers constructed a model of communication in social media and tested the model in 14 Lithuanian HEIs (Zailskaite-Jakste & Kuvykaite, 2012). In Lithuania, *Facebook* is the most common social media site where universities have a presence. This study found that universities with a strong reputation tend to have more *Facebook* fans; however, a large fan-base negatively impacts student engagement. The authors note that communication between business organizations and consumers, consumer-to-consumer communication, and communication between consumer and business organizations (feedback) are the three key aspects of communication on social media in Lithuania and can be successfully applied in the university sector.

Four further papers focus on particular social media platforms such as *Twitter* and *Facebook*. Using content analysis, Peruta and Shields (2017) examined *Facebook* posts from 66 top HE institutions in the US and found differences between posts based on institution type. Based on a study of 106 prestigious Canadian universities (Bélanger et al., 2014), varying levels of activity on *Twitter* were recorded, with a high level of sharing by retweeting (37%). *Twitter* was found to be the most-used platform for conversations between users, whereas *Facebook* was used more for institution-led postings. In a study of six Australian universities, Palmer (2013) high levels of retweeting were also found, which indicated complex interactions between *Twitter* users. Finally, in contrast, in a study of 52 American universities, researchers indicated that *Pinterest* is not being used effectively by institutions. They claim that using *Pinterest* to share images of news and past events is not in line with the best qualities and features of *Pinterest* (Linvill et al., 2015).

The increase in research about social media marketing is not surprising given the exponential growth in the use of these platforms since our original literature review paper was published in 2006. However, the nature of the papers is still somewhat exploratory and concentrates on examining aspects of the uses, popularity, and levels of activity in social media usage by universities and colleges.

2.4.3 Branding, Image, and Reputation

A brand is a symbol, a name, or a distinctive design that identifies a product or a company; and distinguishes the seller's offering based on value (Temple, 2006). Branding enables an organization to develop a sustainable, distinctive identity in the market to achieve competitive advantage (Kotler & Andreasen, 1996). Branding as a research topic results in one of the largest sections for this review (see Table 2.1); 23 papers focused on branding in HEIs and examined the characteristics of universities' branding, factors, and consequences; and a further 13 papers conducted research on a related topic: (brand) image and (brand) reputation which featured in our earlier review (Hemsley-Brown & Oplatka, 2006) (see Appendix 3). Branding was a topic which we recommended in our 2006 paper as a key area for future research. Categories of research include visual images and icons; challenges of applying theories; organizational issues; private sector branding; branding metrics; drivers and strategies for branding; and the benefits and consequences of HE branding.

First, a study of the worldwide branding of universities (Delmestri et al., 2015) examined the images, icons, and logos employed on the Internet to promote HE institutions from 20 countries and five continents. Data were collected from 821 university home pages, and analysis revealed differences between the west and other parts of the globe: more abstract visual types of icons as a means of expression are dominant in the west, but there is a greater diversity of icons, logos and logo types in other parts of the world. Other authors examined icons, logos, trademarks, and brand activities, such as brand equity, brand positioning, and brand identity by universities, to establish what these activities reveal about university branding in the USA (Rooksby & Collins, 2016).

Second, researchers have also pursued a greater understanding of university branding and the challenges of applying theories of branding to universities. Chapleo (2015a, p.8) explored the emergence, development, and growth of the branding of higher education in the UK and concluded that there are clear opportunities to examine branding in the HE context. He claims that although "corporate-, experiential- and internal-branding" from the business sector "have a degree of applicability" for HE "further empirical work is needed."

More recently, research has also examined the branding of UK higher education since the "*Britain is GREAT*" campaign of 1999 (Lomer et al., 2018) to 2014 using a Bourdieusian approach. The authors concluded that the British higher education brand relies on the reputations of its highest quality elite institutions and follows the brand positioning of the nation as a whole—for example, in terms of Britain's objective to achieve international competitiveness.

Third, researchers (Aula & Tienari, 2015) found that university branding is predominantly an organizational purpose and strategy linked to identities and (non-) identification of internal and external players in a socio-cultural and societal context; and others argue there are clichéd brand values associated with the branding of HEIs in Norway and Sweden, with tendencies towards both conformity and differentiation (Sataøen, 2015). Temple (2006) concludes that branding in universities is best described and reputation management ensuring the university has a strong vision, while others (Winter & Thompson-Whiteside, 2017) assert that HEIs are not writing copy for any specific target audience—they claim that references to location tend to mix messages of safety on the one hand, and excitement on the other.

Fourth, as far as private education is concerned, researchers who studied university brands in the private sector found that private and major university respondents were positive about all forms of communications and found them to be more effective than those from more minor universities, who believed that the brochure was the most effective (Judson et al., 2006). However, (Judson et al., 2009) indicated that 343 university administrators from private HEIs reported greater brand clarity in internal brand communications than respondents from public HEIs.

Fifth, measurement has also been the subject of branding research. The work of Chapleo (2007) sought to establish whether branding activity in British universities should be measured and how it should be measured, including the importance of applying metrics as part of university branding strategy (Chapleo, 2011);

Next, in addition, papers are devoted to exploring the factors affecting HE branding in different countries across the globe. Researcher explored the drivers for branding and attitudes towards university brands: the importance of brand promise and brand positioning (Furey et al., 2014); key brand personality positioning according to a further article (Rutter et al., 2017) is based on sophistication, competence, sincerity, ruggedness, and excitement. Further articles focus on the challenges of university branding and the key features that contribute to making university branding different from commercial branding; and how and when universities adopt a branding and re-branding strategy (Baker et al., 2005; Chapleo, 2015b; Fay & Zavattaro, 2016).

Four further research articles on branding strategies found that HEIs need to develop their brand by constructing clear and effective brand architecture, and maintaining coherent and harmonious links within the brand architecture" (Hemsley-Brown & Goonawardana, 2007 p.947); according to more recent research, the university heritage factor also has a greater influence on parents than on prospective students (Rose et al., 2017). Among the barriers to branding are the language skills of international students (Lee et al., 2017) and negative opinions towards the concept of the brand in HEIs due to its commercial connotations (Chapleo, 2007).

Finally, four papers explored the consequences of HE branding in terms of benefits, promises, and mission statements. The researchers indicate that the benefits of branding are differentiating the institution; greater loyalty from staff and students; credibility to charge high tuition fees; and greater loyalty from all stakeholders (de Heer & Tandoh-Offin, 2015); and that mission statements enable universities to claim a market position in comparison with competitors (Kosmützky & Krücken, 2015). Holmberg and Stannegård (2015) further found that the culture of the university explored in the study is marketized managerialism expressed by students who adopted the same idea and language in discussions about their future.

2.4.3.1 Image and Reputation

Related areas of study to higher education branding are image and reputation that are also included in the original 2006 literature review. Brand image is a corporate asset, used to distinguish the organization from the others as well as contributing to sustainability and value creation (Lee & Chen, 2018). Conversely, an organization with a high reputation implies that its achievements considerably exceed that of most of its competitors in one or more particular features. Reputation is the sum of the attitudes and evaluations of stakeholders, students, funding bodies, and government (Steiner et al., 2013).

In the current review, thirteen (13) papers focus on image and reputation, but also on identity, seven of which approach the issues from the demand-side, i.e., the students' side, and the factors affecting their retention. Four of these papers use student satisfaction and retention as variables in their study of institutional image. First, for example, Brown and Mazzarol (2009) report that perceptions of the institution's image have an impact on both perceived value and student satisfaction. Student retention and dropout are also related to perceptions of the institutional image according to later research (Angulo-Ruiz & Pergelova, 2013); institutional image influences both student performance and commitment, which in turn has an impact on students' decisions to dropout.

Chen (2016) explored customer satisfaction in the higher education sector and concluded that positive brand image and student satisfaction lead to positive word-of-mouth, and sharing satisfying experiences is related to loyalty to the institution.

In a study of similar themes, (Saleem et al., 2017) tested the effect of service quality with a sample of 747 students from Pakistani. The findings indicate that the quality of the service is positively related to student satisfaction and university reputation has a moderating effect.

Three further demand-side papers focused on institutional identity. (Tolbert, 2014) examined the extent of the identity of 59 American universities in promotional materials and focuses on its faith (Christian) dimension. Two further papers included other stakeholders in the research design, focusing on university identity in the USA and how this is conveyed to the target audience in the marketing materials (Wolverton, 2006). The second of these identity papers examines whether the corporate visual identity influences a viewer's perception of a university and its lecturing staff (Idris & Whitfield, 2014); researchers found that perceptions of a university [created for the study] were more positive when images of a male lecturer were shown, and reputation and trustworthiness were more positive when a traditional logo was used.

Of the 13 papers which focus on image and reputation, six were concerned with the supply side, i.e., on universities' websites, managers, documents, and executives. Dominant themes were visual or brand image and identity. Thus, (Drori et al., 2016) explored universities' identities and narratives through the visual images, logos, and icons presented on their websites and Lee & Chen et al. (2018) aimed to identify image asset management factors using a Delphi technique, and (Plungpongpan et al., 2016) examined the impact of university (corporate) social responsibility on the brand image of a university.

Three papers merit highlighting in this area of study and focus more on reputation in addition to identity and image. First, (Finch et al., 2013) focused on the attributes and the implications of reputation for three categories of higher education institutions. Second, based on documents from 29 British universities, (Huisman & Mampaey, 2018) asked how universities want students, stakeholders, and the outside work to view them and how similar and distinctive UK universities' images are. Interestingly, despite competition in the UK HE sector, there were few images that deviated from the mainstream, although there were some examples of distinctiveness. Finally, (Steiner et al., 2013) proposed a multidimensional model that identifies internal and external factors influencing university identity and reputation. Accordingly, universities' identities and reputation strategies comprise four dimensions: organizational identity, symbolic identity, image, and reputation.

2.4.4 Marketing Strategy

Marketing strategy is the perception and identification of potential markets and the design of specific tactical approaches for reaching those audiences (Schofield et al., 2013). The topic of marketing strategy in HEIs is the topic of interest for 23 papers in broad terms, covering the topics of utilization and delivery of strategy (5 papers); market orientation (5); segmentation, targeting and positioning (4); marketing mix (4); Recruitment strategy; and relationship marketing (5) (see Appendix 4). Notably, marketing strategy is perception and identification of the potential markets and the design of specific tactical approaches for reaching those audiences (Schofield et al., 2013).

Five marketing strategy papers examined the level of utilization and effectiveness of marketing strategies in universities and colleges (e.g., (Mogaji, 2016) and found that marketing planning and resource analysis are utilized and perceived to be highly effective (Alhakimi & Qasem, 2014); secondly, implementing a successful market strategy is based on a marketing manager's commitment to the strategy and to their role, especially in a highly competitive market (Naidoo & Wu, 2011). Schofield and co-authors (Schofield et al., 2013) found that newer universities in the UK are more influenced by a government policy agenda than older, more traditional institutions, who continue to rely on their reputations while others (Nkala et al., 2014) examined marketing strategies to deal with strong competition for staff and students; they revealed that expectations of service quality and delivery are high among Zimbabwean students, but service experience is low.

2.4.4.1 Market Orientation

Market orientation refers to an organizational culture that prioritizes superior market performances in an organization by creating, and exploiting behaviors that focus on and lead to superior market value for buyers and continuous superior performance for the business (Narver & Slater, 1990). This topic has been explored conceptually or empirically in six papers. Thus, while (Camelia & Marius, 2013) reviewed the literature and discussed the importance of market orientation in HEIs, other researchers explored the level of market orientation in 87 Croatian universities (Pavičić et al., 2009); how market orientation strategies influence international student recruitment performance in Australia (Ross, Grace, Shao, & Mitchell Ross, 2013); and the market orientation and economic performance relationship of universities in India (Baber & Upadhyay, 2015). In contrast, (Alnawas & Phillips, 2014) examined the constructs which constitute the concept of Prospective Student Orientation (PSO) and identified three second-order formative constructs to measure the concept of PSO. Insights from these studies indicate that private universities that face low competition perform better than private universities which operate in highly competitive environments.

Authors (Tayar & Jack, 2013) also conclude that universities are naturally risk averse, in a study investigating the marketing behaviors and perspectives of Australian university managers making decisions about entering international markets. Universities were motivated by simultaneously pursuing increasing income and raising reputation (Tayar & Jack, 2013). Others found that international student recruitment departments of Australian HE institutions largely adopt a customer orientation approach rather than a competitor or inter-functional focus (Ross et al., 2013). In contrast, Croatian universities demonstrate an underdeveloped market orientation despite recognition of the significance of developing stakeholder relationships (Pavičić et al., 2009).

2.4.4.2 Segmentation, Targeting, and Positioning (STP)

Market-oriented HEIs usually engage in market segmentation, develop a marketing mix approach and pay attention to student recruitment. Segmentation is a process of dividing a market into identifiable groups based on their needs, characteristics, or behavior for steering or targeting the marketing effort (Kotler & Armstrong, 2003). Four papers analyze the STP process: one paper explores the use of market segmentation to establish whether this approach improves the utilization of resources (Ghosh et al., 2008); another explores university marketing managers' awareness and perceived importance of market segmentation (Durkin et al., 2014); McAlexander et al. (2016) demonstrate the importance of using a segmentation and targeting approach for identifying and engaging with alumni to maximize alumni giving; finally, authors also focus on the market positioning of Australian universities (Mazzarol & Soutar, 2008). STP authors recommend improved use of resources and the adoption of targeted marketing strategies and highlight the lack of awareness and failure to capitalize on the use of online communications to target and communicate with more mature prospective students. Authors also note, however, that it is increasingly difficult for universities to maintain quality and growth in a context where reduction in spending is also a priority (Mazzarol & Soutar, 2008).

2.4.4.3 The Marketing Mix

Three (3) authors explored the application of the marketing mix and the marketing communications mix as approaches to the marketing of HEIs. The 4Ps have a special place in the marketing mix, and each of them affects the buyers in one or several phases of consumption. The marketing mix refers to the "4Ps" which are defined as Product; Price; Place, and Promotion. Authors have also added a 5th P: People; and by also adding two additional Ps: "Process," "Physical evidence," 7Ps model is an adapted model of the marketing mix for services marketing (Enache, 2011).

First, the application of the 7Ps framework is used to gain a better understanding of the Romanian higher education market (Enache, 2011). In contrast, Artur (2015) focused specifically on strategic marketing communications activities and the role and importance of the Internet specifically, in the marketing activity of higher education institutions in Poland; and (Moogan, 2011) similarly sought to identify the key marketing communications mix activities needed to meet students' needs when applying to university to inform university marketing managers. While a study of the 7Ps model is somewhat limited in scope, the conclusions from the studies on marketing communications mix strategies unsurprisingly highlight the importance of online communications. In defense of these conclusions, perhaps—the papers are more than five years old, and marketing communications has moved on apace since 2011—and even since 2015.

2.4.4.4 Relationship Marketing Strategy

A major concept in the marketing of services and educational organizations refers to relationship marketing, a strategy where the management of interactions, relationships, and networks are fundamental for interaction with buyers (Grönroos, 1997). Yet, only five papers focused specifically on this concept, none from the UK or the USA, and the studies largely examined the antecedents to institutional loyalty. Thus, a study from Brazil tested the association between relationship quality and loyalty to an institution and found that the strongest contributing variable to student customer loyalty is the perceived quality of the institution (de Macedo Bergamo et al., 2012). Purgailis and Zaksa (2012) examined the relationship between service quality and student loyalty to a university in Latvia; Schlesinger et al. (2017) examined the role of brand image, trust, satisfaction, and shared values as a direct and indirect explanation of alumni loyalty in Spain; one conceptual paper further analyses the relationship between alumni loyalty and relationship marketing (Iskhakova et al., 2017).

Finally, in Korea, (Kim et al., 2010) research found that students' strong identification with their sports program is positively related to their strong identification with the university as a whole and leads to a sense of belongingness & support for the university.

In sum, the topic of relationship marketing goes beyond loyalty to an institution, however, and offers potential for research on trust, commitment, and long-term support for institutions; in addition to studies on partnerships with international institutions, use of technology for managing relationships and data analytics, and risk, salience, and emotional bonds in relationships. A related topic of research in this respect is alumni management which is the final topic of this review.

2.4.5 Recruitment, Alumni, and Gift-Giving

Finally, papers were identified which focus on marketing for recruitment purposes, management of alumni, and the related topic of gift-giving (see Appendix 5). Alumni or previous students are the best ambassadors, advocates, and volunteers who can also be mentors, help to build enrolments, actively recommend the institution, and be enthusiastic fundraisers (Pedro et al., 2018). This is allied to gift-giving and donations, which refer to the monetary contributions made to an institution by its alumni (Stephenson & Bell, 2014).

The topic of student choice is considered substantial, and a review of literature has been published elsewhere (Hemsley-Brown & Oplatka, 2015b), therefore recruitment, the process of identifying, targeting, attracting, and managing the enrolment of students to the institution (Mortimer, 1997), is only included when there is a marketing, not choice focus.

Five papers focused on student recruitment strategies of HEIs: how these strategies are linked to a university's market position (Frølich et al., 2009); and what emerging universities can learn from the strategies employed by established universities regarding student recruitment (Onk & Joseph, 2017). Two papers focus on international recruitment agents, asking how agents justify their value and why universities are employing agents (Hulme et al., 2014), including their export market orientation (Asaad et al., 2015), while another explored the way ethnic minorities and racial groups are portrayed in university recruitment materials (Pippert et al., 2013). It is somewhat surprising that there are so few papers on international recruitment strategy, given the high level of international recruitment activity in universities around the world. We acknowledge that with different search criteria, perhaps more papers on this topic might emerge.

Papers on alumni (two papers) and gift-giving (two papers) are new topics for the review compared with our last review. One paper focuses on elements of an effective strategy for alumni management, and the second focuses on factors that encourage alumni to develop a sustained relationship with the institution. First, Alnawas and Phillips (2015) examine and test the concept of alumni orientation (AO) in UK universities and identify nine multi-item components to measure AO.

They offer a model of AO and emphasize the importance of database management, social media management, and events management in successful alumni relations. Second, a propensity to form a strong alumni relationship is based on a positive attitude to making a commitment to an alumni relationship, good communication, and satisfaction with both the social and academic environment while students are studying at the institution (Pedro et al., 2018). Both papers on gift-giving are based in the USA. The focus of both gift-giving papers is the motivation for gift-giving, and identifying the reasons alumni make donations (Stephenson & Bell, 2014; Stephenson & Yerger, 2015). Both papers use a very large sample for the study and conclude that motivation for alumni donating is explained by using social identity theory (Stephenson & Bell, 2014); and satisfaction with university resources is associated with the positive brand association and brand image, which increases the likelihood of gift-giving (Stephenson & Yerger, 2015).

The next section examines the differences between the 2006 review and the current review; and identifies HE marketing topics—potential topics, which are missing from the current searches based on examining and comparing topics that are currently the focus of research on marketing outside the HE sector.

2.5 Discussion

Looking back at our paper from 2006 (Hemsley-Brown & Oplatka, 2006) and comparing the current review with the review from 14 years ago, a number of striking differences between our first review of the literature and the current review arise. First, not unexpectedly, the number of hits during searches has increased to the extent that we had to be more specific in our search terms (largely to exclude research on pedagogy in HE). We also searched separate topics based on headings from the previous review and new topics which emerged from these searches. The earlier review identified 63 papers (empirical and theoretical), and the current review: 105 (empirical and theoretical); we also excluded "opinion" papers in both reviews, and excluded some papers based on single-institution samples due to generalizability issues. Above all, the current review emphasizes our conclusion that HE marketization is here to stay and extends to other areas due to increased competition among HEIs and the continuing need for image- and brand-building.

Second, new topics and sub-topics emerged from this review, compared with the previous review; and one topic was no longer the focus of study in marketing HE (widening participation). New topics are social media marketing, branding, strategic marketing, marketization, alumni and gift-giving, and the original themes are expanded—particularly all aspects of marketing communications, which has a new focus on online communications. Marketization, branding, and social media marketing are the central focus of papers in HE marketing during the period 2005–2019. However, in this respect, we have a number of observations and recommendations:

(1) Marketization research, which is predominantly "critical marketing" on the topic, reveals that most papers are conceptual rather than empirical. This field could expand into more empirical research, conceptual modeling for empirical research, and a stream of robust empirical evidence for some of the concerns and claims associated with this phenomenon, which is now a global issue.

(2) Although some authors debate the weaknesses and deficiencies of the adoption of a market concept in HE, there are limited conceptual articles arguing in support of the effective application of market concepts and marketization of HE. Conceptual papers tended to take a critical stance against the market in HE, while empirical papers tend to accept the irrevocability of the free market without challenge as a rationale for their research. This can generate, among other things, a sense of uncritical acceptance with current marketization in HE in terms of empirical research.

(3) There is also potential to examine specific elements or dimensions of marketization in more focused, empirical studies. In doing so, researchers may shed more light on the complexity of market concepts in HE and their inherent contradictions regarding education experience and management approaches.

Third, research in branding has also expanded considerably during this period and there is potential to extend research in this field further by considering the study of more focused elements or dimensions of branding currently and previously the focus of research in marketing in other sectors. For example, brand attachment (Grisaffe & Nguyen, 2011; Park, 2016); brand proposition (Lee et al., 2017); brand trust (Chaudhuri & Holbrook, 2001; Lombart & Louis, 2010); brand commitment (Chouthoy & Kazi, 2016; Shuv-Ami, 2012); and brand personality (Lombart & Louis, 2010). A recent edited book covers strategic brand management in higher education, and includes sections on brand strategy, planning, and measurement—chapters on measurement, covering scale development and evaluation of scales in HE branding, also offer a valuable resource and starting point for further research in the field of HE branding (Nguyen et al., 2019). In contrast, the broader study of marketing strategy is relatively fragmented, consisting of several sub-fields of research, each of them encompassing a small amount of empirical work (e.g., the marketing mix, market orientation, segmentation research). This reflects, by and large, the initial stages of intellectual maturity that characterize the study of HE marketing and may change in the future as more younger scholars join the field and extend its areas of interest.

Notably, when looking at the type of the papers, the knowledge about HE marketization has been produced mainly by conceptual papers. In contrast, the other four streams of research have employed both quantitative and qualitative research designs. Thus, 46 empirical works have used the former design. More accurately, 10 out of 20 papers about marketing communication, advertising, and social media, 14 out of 36 papers about branding, image and reputation, 15 out of 23 papers about marketing strategy, market orientation, segmentation and marketing mix/relationships marketing, and 7 out of 9 papers about recruitment, alumni and gift-giving are quantitative.

Fourth, the topic of social media marketing is still in its infancy in some respects, and more empirical studies are required to improve understanding of social media marketing and wider marketing communications methods, using more ambitious research approaches. To date, papers tend to be exploratory, examining media use, popularity, and levels of activity. Although research exploring usage, engagement, and types of engagement offer valuable insights, there are further topics currently of interest in the wider marketing literature that still need further study. These topics relate to sharing, co-creation of content, and experience. For example, co-creation of content (Fujita et al., 2019); media message sharing (Ordenes et al., 2019); user-generated content (Roma & Aloini, 2019); social network mechanisms (Levitan, 2018); online brand communities (Munjal et al., 2019); consumer empowerment (Bachouche & Sabri, 2019); user-sharing (Chen et al., 2018); and how these contribute to value for users.

Finally, our review is a second attempt to chart the progress of the current research in the study of marketing in higher education. Future reviewers of this field will probably have much more work to do, as the field is only in its incipient phases of scholarly development. A future review might be needed to examine the literature in only one of the key fields we identified due to the anticipated rapid expansion of published literature in the broader field of HE marketing.

Appendix 1 Summary of articles on marketization for the literature review

Authors, date	Sample	Method	Summary	Results
The Marketization of Higher Education				
Bowl, 2018	4 universities (2 in New Zealand, and 2 in the UK)	Qualitative: Document content analysis	How do universities balance the need to maintain a successful global brand (e.g., elitism) with national expectations (e.g., equality and fair access).	Differentiation is fundamental for the communication strategies of universities. Distinctiveness is essential in a marketing strategy, but also implies exclusiveness. Commitment to social inequality is muted in marketing communications while performance is highlighted.
Brown, 2008	N/A	Conceptual paper	What are the implications, benefits, and limitations of the marketization of higher education?	Competition is beneficial in terms of responsiveness, innovation, and efficiency. Marketization has limitations, particularly regarding course quality and the provision of sufficient information for customers. Marketization contributes to polarization, particularly in terms of social class.
Cardoso et al., 2011	N/A	Qualitative: Content analysis of newspaper advertisements	The study aims to determine whether the political change in public and private universities and polytechnics in Portugal is transforming students into consumers.	Press advertisements sought to stimulate demand low to high levels of aggressive tactics. Many institutions, particularly private colleges, used more aggressive and intrusive announcements.
Craven & Anne, 2012	N/A	Conceptual	The discussion focuses on social justice, particularly the unfairness of markets for students from lower socio-economic groups in the UK.	Facilitating access to higher education for disadvantaged groups is not sufficient; institutions must also focus on student retention and progression for these students.

Favaloro, 2015	N/A	Conceptual	Examines growth in student numbers and marketing investment patterns in Australian universities.	Prestige universities are much less affected by a highly competitive environment than other universities; non-prestige universities also face competition from non-university providers.
Gibbs, 2007	N/A	Conceptual	Sets out an argument against advertising as a part of the marketing of higher education on the basis that it goes against critical thinking and should be avoided on moral grounds.	Argues that advertising intends to persuade rather than inform, and is intrusive and manipulative, which is against the purpose of education, which is for the common good.
Gibbs, 2018	N/A	Conceptual	Challenges the marketization of higher education and sets out the damage and dissatisfaction it has wrought on education itself.	Consumerism changes learners into customers, tutors into service providers, and higher education has become competitive rather than collaborative; therefore trust in higher education has now been undermined, and dissatisfaction is the result.
Hemsley-Brown, 2011	N/A	Conceptual	Examines the potential damage the market can inflict on higher education and raises concerns that the core values of higher education are in conflict with the market	A combined market and government interventionist approach is necessary for the benefit of those who are doubtful or unable to participate in HE—particularly where there are financial barriers.
Lowrie & Hemsley-Brown, 2011	N/A	Conceptual	Focuses on the concept of marketization, makes a comparison with marketing and explains the differences.	Discusses the emerging themes and characteristics of marketization including an increase in the complexity of HE; the expansion of a consumerist dialog; a focus on rankings; and the importance of image, identity, and brand.
Mause, 2009	N/A	Conceptual	The author discusses the problems which arise through excessive marketing signaling in a highly competitive higher education market.	The author highlights the lack of progress by economists in identifying and measuring the harmful and beneficial effects of market signaling in the HE context.

Miller & Brian, 2010	N/A	Conceptual	The author analyses definitions of the commodification of higher education and identifies what universities are selling.	The author concludes that the commodification of higher education is already well established, but outcomes based on values, principles, and liberalism are on the decline in favor of credentials, skills, and financial gain.
Molesworth et al., 2009	N/A	Conceptual	The purpose of the paper is to explore Fromm's argument that students in higher education no longer seek to "be learners," but rather aim simply to "get a degree."	The marketization of higher education has led to a decline in intellectual complexity of content and a greater focus on the workplace and employability issues.
Natale & Doran, 2012	N/A	Conceptual	Higher education was once a public good, but is now a commodity.	Academic freedom is considered less important than accountability; trust less important than utility; performance and self-interest are more important than introspection.
Newman & Jahdi, 2009	N/A	Conceptual	The reasons behind the shift to marketization and a focus on marketing and the impact on staff and universities.	The authors argue there is now an increasing focus on the 4Ps[a] of higher education marketing and a decline of those in HE who challenge the marketization of education.
Susanti & Dewi, 2011	N/A	Conceptual	Explores the impact of the marketization of higher education in Indonesia in the context of new regulations.	Criticizes regulations for failing to address educational inequity and the impact of privatization and marketization academic values and the purpose of higher education.
Symes & Drew, 2017	50 advertisements (Australia)	Qualitative: Content analysis of advertisements.	Provides a critical analysis of advertisements for universities in a climate of high competition inspired by neo-liberalism.	Advertisements reveal careerist, vocational images dan messages portraying a university as a higher level technical college rather than a university.
Weymans & Wim, 2010	N/A	Conceptual	The authors discuss a possible alternative to market orientation and traditional universities by examining key dimensions of a democratic culture.	The authors argue that a market-orientated HE culture stifles creativity, professional debate, and professional judgment.

Source: The authors
[a]The 4Ps of the marketing mix: product, price, promotion, and place.

Appendix 2 Summary of articles on marketing communications, advertising, and social media marketing for the literature review

Authors, date	Sample	Method	Summary	Results
Marketing communications, advertising and social media marketing				
Marketing Communications				
Adams & Eveland, 2007	150 university Web sites	Qualitative: Content analysis of web pages	Websites were used to divide institutions into three groups: accredited residential, regionally accredited online, and non-accredited online. Promotional imagery, marketing messages, and marketing themes were analyzed for similarities and differences.	Accredited residential institutions were not utilizing advantages in order to differentiate their institutions from online accredited and non-accredited institutions.
Bonnema & Van der Waldt, 2008	716 prospective students	Quantitative survey	To determine whether marketing messages need to be different for each market segment and identify the information needs of segments of prospective students.	Key factors identified are employability, course content, student experience, sport opportunities, media and social sources. Marketing should target individual sub-groups of students.
Edmiston-Strasser, 2009	42 US universities; 9 interviews	Qualitative and quantitative: Mixed methods survey and interviews	Examined whether integrated marketing communications is applied in universities in the USA, and the process of IMC (integrated marketing communications).	Institutional leadership was shown to be the most important determinant of whether integrated marketing communications (IMC) was in place in universities. IMC also needs to work alongside institutional branding and reinforce the branding equity of the institution.

Gribanova, 2016	N/A	Conceptual paper	An exploration of developments in mobile marketing communications technology tools and the benefits to universities in engaging with these methods to communicate with students and prospective students.	The authors recommend that universities adopt new mobile marketing communications tools both for information dissemination and engaging with target students.
Pizarro Milian & Davidson, 2018	43 home pages (Canada)	Qualitative and quantitative: Mixed methods content analysis	An examination of the content of symbolic images in promotional materials: a comparison of different types of HE institutions.	Public universities emphasize research achievements and rankings, while colleges tended to focus on short phrases and catchy tag lines.
Popović, 2015	131 HEIs (Serbia)	Qualitative: Content analysis of web pages	The study focuses on which types of marketing communications are used by HEIs, how effective they are and whether they are integrated.	The findings indicate that marketing communications are not integrated; the researchers recommend more exploitation of interactive communications.
Royo-Vela, 2016	121 student respondents (Spain)	Qualitative and quantitative:	The study seeks to identify how universities can develop to improve their image by using social media tools	The findings show that: advertising, word-of-mouth, content, and information about HEIs are the main influences on decisions.
Schüller & Chalupský, 2011	20 marketing managers (Czech Republic)	Survey and interviews	What are the problems for university marketing communications, and how is marketing communications organized?	The research identified management structure problems in the universities/faculty relationship and suggests that faculties should have more responsibility for marketing communications.
Vuori, 2015	68 homepages of universities (Finland)	Qualitative: content analysis of web pages	Explores how HEIs in Finland convey market differentiation on webpages targeted at prospective students.	Websites emphasized the relevance of programs for employability and career prospects in addition to an international experience and context.
Advertising				
Clayton et al., 2012	115 American higher education institutions	Qualitative: Content analysis of advertising material	This research explores the message strategies of institutional communications by US universities' schools of sports.	The advertising model identified five themes the institutions use in messaging: campus characteristics, academics, co-curricular activities, prestige building, and mission/purpose.

(continued)

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Jan & Ammari, 2016	350 Malaysian prospective students	Quantitative survey	Examined the impact of online advertising on prospective students.	Intrusive advertisements on university websites have a negative impact on student's selection of a university.
Papadimitriou & Ramírez, 2015	5 campaigns	Qualitative: Content analysis of advertising materials	Explores the main marketing messages in university advertising campaigns in five cities worldwide.	The most salient content of advertisements were: students; logos; global scope, open campus, and careers and the similarity across cities was notable.
Social media marketing				
Bélanger et al., 2014	106 Canadian university social media sites	Qualitative: analysis of data from social media sites	Studies the social media of Canadian universities to examine institutional branding strategies for recruitment of home and overseas students.	Utilizing a campus newsfeed strategy is the most frequently used strategy by Canadian universities (50%). More elite schools are highlighting the results of research by faculty, which attracts students who aspire to join a prestigious university.
Brech et al., 2017	159 university social media websites	Quantitative: analysis of social media data	Drawing on theories of self-presentation and community engagement, the authors develop a theoretical model to explain engagement with social media marketing and the outcome factors.	Universities with a strong reputation tend to have more Facebook fans; however, a large fan-base negatively impacts on engagement.
Brendzel-Skowera & Lukasik, 2016	16 Polish universities	Quantitative: analysis of social media data	To identify how universal the use of social media sites is for Polish universities.	Facebook is the most common sites for universities in Poland to have a presence. Most interaction is with students and potential students and attempts to encourage two-way communication.
Clark et al., 2017	24 respondents (USA)	Quantitative: survey	The research examines whether social media engagement impacts on relationship quality in relation to universities and students.	The results show a positive relationship between the extent to which students follow a university on social media and their perception of establishing a high-quality relationship with their university. Using several multi-media platforms to follow a university leads to higher perceived relationship quality.

Linvill et al., 2015	52 university Pinterest accounts (USA)	Qualitative: Content analysis of social media accounts	The study used content analysis to develop a typology of university pins based on information sharing, community, group experience and promotion.	Findings indicate that Pinterest is not being used effectively by institutions. Using Pinterest to share images of news and past events is not in line with the best qualities and features of Pinterest.
Palmer, 2013	6 universities' Twitter sites (Australia)	Quantitative: analysis of social media accounts	An examination in the use of Twitter by Australian universities.	Varying levels of activity on Twitter were recorded, and a high level of retweeting (sharing) relies on the number of followers.
Peruta & Shields, 2017	Facebook posts 66 universities (USA)	Qualitative: Content analysis of Facebook posts	Differences in postings by frequency and type level of engagement based on the type of institution.	The type of institution is a factor in Facebook posting strategies and type of engagement. Photos are less frequently posted by liberal arts colleges.
Zailskaite-Jakste & Kuvykaite, 2012	14 HEIs (Lithuania)	Qualitative: Case study and content analysis	The aim of the study was to build a model of communication in social media and to test the model in public higher education institutions in Lithuania.	Findings show that three aspects of communication in social media are key: communication between business organizations and consumers; consumer-to-consumer communication; communication between consumer and business organizations (feedback).

Appendix 3 Summary of articles on branding, image, and reputation for the literature review

Authors, date	Sample	Method	Summary	Results
Branding, image, and reputation				
Branding				
Aula & Tienari, 2015	Convenience sample of 3 HE institutions involved in a merger	Qualitative: Content analysis of stakeholder texts and in-depth interviews	Analyses data from one new university created in a merger argue that branding is characterized by different interests among players, with different means to influence brand development.	University branding is predominantly an organizational purpose linked to identities and (non-)identification of internal and external players in a socio-cultural and societal context. It goes beyond marketing and marketing communications.
Baker et al., 2005	490 respondents	Qualitative: focus groups with faculty and staff	Research focuses on understanding the drivers for attitudes towards university brands.	People construct their own beliefs about University corporate partnerships, and this is not necessarily related to reality. The respondents held both positive and negative views about the benefits of university corporate partnerships.
Chapleo, 2007	Judgment sample of 15 respondents	Qualitative interviews with executives of UK universities	To explore current knowledge and opinion of issues and perceptions of potential and actual barriers to branding by academics in UK universities.	Reputation is viewed as distinctly different from brand, which has commercial connotations. Brand is a less favorable term in an HE context due to commercial associations. However, CEs perceived their own institution as having a distinctive brand.
Chapleo, 2011	In-depth Interviews with 20 managers	Qualitative interviews with marketing managers of UK universities	Seeks to establish whether branding activity in universities should be measured and how it should be measured.	Universities, on the whole, have not found commercial approaches to branding helpful or relevant to the complex contexts of a university. Newer universities were more able to use the commercial definition of branding than older universities, where the concept of reputation was a closer match with their activities.

Chapleo, 2015a	A snowball sample of 15 managers	Qualitative interviews with marketing managers of UK universities	To gain a clearer understanding of university branding and the challenges of applying theories of branding to universities.	An overall conceptual model of branding for universities remains elusive since commercial branding models are not a good fit. Corporate branding and experiential branding have some applicability to universities.
Chapleo, 2015b	55 respondents from 32 UK universities	Qualitative: interviews with managers from UK universities	Explore the challenges of university branding and the key features that contribute to making university branding different from commercial branding.	Universities are considered too complex to apply a commercial branding model, particularly for stating a concise brand proposition. The complex nature of higher education and the multiple stakeholders means that conventional branding models are limited.
de Heer & Tandoh-Offin, 2015	2 case study universities in Ghana; 50-minute interviews	Qualitative and quantitative: (interviews and secondary data analysis)	The study examines the benefits of university branding and whether enhanced performance and increased recruitment of students and faculty result from a successful branding strategy.	The benefits of branding are: differentiating the institution; greater loyalty from staff and students; credibility to charge high tuition fees; and greater loyalty from all stakeholders.
Delmestri et al., 2015	821 university home pages	Qualitative: Content analysis of university icons and visual images	The study examines universities' branding and visual self-representation, in an international context. The focus is on the images, icons, and logos employed on the Internet to promote the institutions.	Findings show that more abstract visual icons are expression has dominance in the west, but there is a greater diversity of logos and logo types in other parts of the world.
Fay & Zavattaro, 2016	109 HEIs (USA)	Quantitative: secondary data analysis dyadic event history analysis	Examines whether changes in tenure and increased teaching loads have affected institutional branding initiatives. Focuses on how and when universities adopt a branding and re-branding strategy.	Private universities are early adopters of branding strategies, but they are not followed by their public university counterparts. Universities tend to re-brand as their performance and income increase.
Furey et al., 2014	35 interviews with university managers; 85 websites	Qualitative: Inductive content analysis and interviews	To explore the nature of different brand promises in different types of universities in the UK.	There is evidence of the application of branding, and brand promise. Key themes provide the basis of distinctions between universities: environment, experiences, status, heritage and global positioning

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Hemsley-Brown & Goonawardana, 2007	30 respondents and 2 managers	Qualitative and quantitative: applicant data analysis; in-depth interviews	The study aims to examine key factors in the development of a university and business school brand in an international context and focuses on the development of the brand architecture.	The findings indicate that universities need to articulate and develop their brand by constructing clear and effective brand architecture and maintaining coherent and harmonious links within the brand architecture.
Holmberg & Stannegård, 2015	32 interviews; and secondary data sources	Qualitative and quantitative interviews; content analysis from documents	Explores the benefits of university branding as a way of supporting students' self-branding and brand identity.	The culture of the university school was identified as marketized managerialism, which was reflected in the students who adopted the same ideas and language in discussions about their future.
Judson et al., 2006	157 respondents	Quantitative survey	Investigates the internal communication of the university brand using a sample from private, major and mid-major universities.	Private and major university respondents were positive about all forms of communications and found them to be more effective than those from less major universities, who believed that the brochure was the most effective.
Judson et al., 2009	343 university administrators	Quantitative survey	The study focused on how well university administrators understood their university brand and whether they implemented their knowledge of the brand as part of their role.	Respondents from private HEIs reported greater brand clarity in internal brand communications than respondents from public HEIs.
Kosmützky & Krücken, 2015	110 university mission statements	Qualitative: Content analysis and discourse analysis of institution texts	Do university mission statements differentiate the institution from its competitors?	Results show that mission statements enable universities to claim a market position in comparison with competitors that highlights both the similarities with other universities and the differences.
Lee et al., 2017	Historical statistics on international students in Korea	Quantitative: Statistical secondary data analysis	The purpose of the study was to identify the key factors associated with brand satisfaction from a student perspective.	International students who are able to integrate with their peers through a high level of language skills (e.g., English) are more likely to be satisfied with their school and study program.

Lomer et al., 2018	N/A	Conceptual	Explores the emergence, development, and growth of the branding of higher education in the UK since the "Britain is great" campaign of 1999.	The development of the branding of higher education in Britain was a commodification of HE and stressed the elitism and high quality of British education, targeted at international students.
Rooksby & Collins, 2016	10265 university trademarks (USA)	Quantitative and qualitative: analysis of multiple datasets	To explore trademarks and brand activities by universities to establish what these activities reveal about university branding.	Universities continue to use trademarks as a way of positioning their institutions in the market and to support market value and market signaling.
Rose et al., 2017	127 students; 240 respondents;	Quantitative surveys	The role of university heritage in marketing communications of universities.	Developed a measure for brand heritage; the heritage factor had a greater influence on parents than on prospective students.
Rutter et al., 2017	10 university prospectuses (UK)	Qualitative: Content analysis of prospectuses	The study seeks to explore how brand personality is communicated in the marketing communications of universities.	The study identifies key brand personality positioning based on sophistication, competence, sincerity, ruggedness and excitement.
Sataøen, 2015	39 and 36 HEIs (Norway and Sweden)	Qualitative and quantitative content analysis of prospectuses	The research studies how different core values are used in the branding of universities in two countries.	Findings suggest there are clichéd brand values associated with the branding of HEIs of the two countries and tendencies towards both conformity and differentiation.
Temple, 2006	N/A	Conceptual	Examines the meaning of branding and presents a case using examples to analyze the current so-called branding activities of universities.	Concludes that branding in universities is best described and reputation management and ensuring the university has a strong vision.
Winter & Thompson-Whiteside, 2017	15 HEI managers (UK); 105 prospectuses (UK)	Qualitative: content analysis	The study explores how universities of different types exploit an HEI's location in their marketing.	HEIs are not writing copy for any specific target audience; references to location tend to mix messages of both safety and excitement.

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Image and reputation				
Angulo-Ruiz & Pergelova, 2013	Random sample of 396 students	Quantitative: survey	To develop and test a student retention model including system and institutional dropout as outcome variables and examines differences in factors that affect them. Models the image of the institution as an influence on institutional commitment and dropout intention.	Early personal and institutional characteristics (e.g., higher education institutional image; students' goal commitment), institutional experience and integration of students to the academic environment influence the level of student performance and institutional commitment, which further influence dropout decisions.
Brown & Mazzarol, 2009	373 student respondents	Quantitative: survey (Partial Least Squares)	The study focuses on customer satisfaction as a driver for loyalty in higher education settings in Australian universities.	Institutional image positively predicted perceived value and student satisfaction
Chen, 2016	115 former HE students in Taiwan	Quantitative: survey	The research explores brand image, loyalty, and positive word-of-mouth: sharing satisfying experiences and recommendations to others.	Brand image is significantly related to loyalty. University students' brand image, satisfaction, and loyalty positively influence the sharing of satisfying experiences and making recommendations to others.
Drori et al., 2016	826 university home pages	Qualitative: Content analysis of internet front page icons	The research seeks to study universities' identities and narratives through the visual images, logos, and icons presented on their websites.	Four institutional narratives are identified: guild-like classic, professional scientific, localized national pride, and universal organization narrative.
Finch et al., 2013	30 manager respondents; 164 manager respondents	Mixed methods: interviews and quantitative survey	The research focuses on the attributes and the implications of reputation for three categories of higher education institutions.	Findings indicate that each category of higher education institution displays distinctly different reputational attributes which facilitate competitiveness in the market.
Huisman & Mampaey, 2018	Documents and websites from 29 UK universities	Qualitative and quantitative: content analysis	The study focuses on asking how universities want students, stakeholders, and the outside work to view them: how similar and how distinctive are UK universities' images?	Despite competition in the UK HE sector, there were few images that deviated from the mainstream, although there were some examples of distinctiveness.

Idris & Whitfield, 2014	888 international respondents	Quantitative: survey	The study focused on whether the corporate visual identity influences a viewer's perception of a university and its lecturing staff.	The study found that perceptions of a university [created for the study] were more positive when images of a male lecturer were shown, and reputation and trustworthiness were more positive when a traditional logo was used.
Lee & Chen, 2018	5 discussants and 15 respondents	Qualitative: Delphi methodology	The study aimed to identify image asset management factors using a Delphi technique.	The study found that in terms of asset management, stakeholder image and student image were a top priority for managers in HEIs.
Plungpongpan et al., 2016	6 parents and 6 students from 3 universities (Thailand)	Qualitative: interviews	Examines the impact of university corporate social responsibility (USR) on the brand image of a university.	University corporate social responsibility (USR) is not a factor in the choice of university and is not very visible to prospective students, but it is viewed positively and needs more effective marketing.
Saleem et al., 2017	747 students (Pakistan)	Quantitative: survey	To test the effect of service quality on student satisfaction and the moderating effect of university culture, price, and reputation.	Service quality positively relates to student satisfaction and is strengthened by the culture; price and reputation negatively impact this relationship.
Steiner et al., 2013	N/A	Conceptual	The theoretical paper develops a multidimensional model identifying internal and external factors influencing university identity and reputation.	Universities' identities and reputation strategies comprise four dimensions: organizational identity, symbolic identity, image, and reputation.
Tolbert, 2014	59 institutions (USA)	Qualitative: Content analysis of marketing materials	The research focuses on to what extent the branding of university focuses on its faith (Christian) dimension.	Findings show that focusing on faith in marketing materials was low: 14%-20% on home pages and 18%–19% on admissions materials.
Wolverton, 2006	3 business schools (USA)	Qualitative: Descriptive case research	The study focuses on university identity and how this is conveyed to the target audience in the marketing materials.	Institutional identity was used to identify institutional strengths, which in turn were used for targeting marketing based on the institutional identity.

Source the authors

Appendix 4 Summary of articles on marketing strategy, market orientation, segmentation, targeting and positioning, marketing mix and relationship marketing for the literature review

Authors, date	Sample	Method	Summary	Results
Marketing strategy, market orientation, segmentation, targeting and positioning, marketing mix and relationship marketing				
Marketing strategy				
Alhakimi & Qasem, 2014	21 managers from universities in Yemen	Qualitative and Quantitative: survey and descriptive analysis	This study examined the level of utilization and effectiveness of marketing strategies in private universities recruiting undergraduate students.	Positive and significant relationships were found between usage and perceived effectiveness of marketing strategies. Marketing planning and resource analysis were utilized and perceived to be highly effective; a market segmentation strategy was least utilized.
Mogaji, 2016	134 university websites (UK)	Qualitative: Content analysis of webpages	The purpose of the paper is to scrutinize the marketing strategies adopted by UK universities on their websites at the end of the recruitment process.	During the last stages of recruitment, most universities substantially revised their websites to focus on student satisfaction, employability and availability of accommodation
Naidoo & Wu, 2011	570 marketing managers	Quantitative: survey (SEM)	The study explores the implementation of internal marketing strategies in universities.	Implementing a successful market strategy is based on a marketing manager's commitment to the strategy and to their role, especially in a highly competitive market.
Nkala et al., 2014	80 academics (Zimbabwe)	Qualitative: interviews using content analysis	Examines the service quality strategies universities in Zimbabwe are using the challenge competition in higher education.	Findings suggest that expectations of service quality and delivery are high among Zimbabwean students, but service experience is low.
Schofield et al., 2013	19 institutions (10 HE; 9 FE) (UK)	Qualitative: inductive thematic analysis	The research study examines the marketing strategies of different types of higher education institutions.	Newer universities are more influenced by a government policy agenda than older, more traditional institutions that continue to rely on their reputation.

Market orientation				
Alnawas & Phillips, 2014	21 in-depth interviews; 13 pilot study respondents	Qualitative and quantitative: interviews; and survey	To conceptualize, and empirically examine the constructs which constitute the concept of Prospective Student Orientation (PSO). The study identified three second-order formative constructs to measure the concept of PSO.	The measurement instrument for PSO, (36 items) was valid and reliable using 6 multi-item components: information generation; information use; inter-functional coordination; intra-functional coordination; managing recruitment / promotional activity; and managing prospective.
Baber & Upadhyay, 2015	119 respondents from private universities in India	Quantitative: survey	The study examines the relationships between market orientation and the economic performance of universities in Indian.	Private university environments with low competition perform better than private universities which operate in highly competitive environments.
Camelia & Marius, 2013	N/A	Conceptual paper	Reviews the literature and discusses the importance of market orientation in higher education institutions.	One of the most important benefits of a market orientation strategy is the increased performance of the institution. Other improvements include increased enrolments and retention of students.
Pavičić et al., 2009	87 university staff (Croatia)	Quantitative survey	How market oriented are Croatian universities, and how far do they gather information appropriate for different stakeholders?	Croatian universities demonstrate an underdeveloped market orientation despite recognition of the significance of developing stakeholder relationships.
Ross et al., 2013	159 international recruitment practitioners (Australia)	Quantitative: survey	The study examines market orientation strategies (by individual components) to establish how they influence international student recruitment (ISR) performance.	The findings show that ISR departments of HE institutions largely adopt a customer orientation approach rather than a competitor or inter-functional focus.
Tayar & Jack, 2013	4 university case studies (Australia)	Qualitative: data analysis	The researchers examine investigate the behavior and perspectives of university managers making decisions about entering an international market.	The case universities were motivated by income and a quest for a prestigious reputation; they were risk averse and influenced by past mistakes.

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Segmentation Targeting and Positioining (STP)				
Durkin et al., 2014	8 marketing managers; 10 websites	Qualitative: data analysis and content analysis	Explores university marketing managers' awareness and perceived importance of market segmentation, in particular segments of more mature students and the use of the Internet for marketing communications.	Highlights the lack of awareness and failure to capitalize on the use of online communications to target and communication with more mature prospective students.
Ghosh et al., 2008)	Secondary data 16,000 students	Quantitative: secondary data analysis	Exploratory research to establish whether using segmentation analyses offers improved use of resources and adoption of a targeted marketing strategy.	Cluster analysis of enrolment data resulted in five distinct segments based on ten segmentation variables.
Mazzarol & Soutar, 2008	258 HE institutions (Australia)	Quantitative: data analysis (cluster analysis)	Explores the market positioning behavior of Australian universities to examine whether the strategy impacted their competitiveness in the market.	The findings indicate that it is difficult for universities to maintain quality and growth with a simultaneous cost-cutting strategy, especially in a context of high competition.
McAlexander et al., 2016	4834 alumni (2 US universities)	Quantitative: survey	The study examines the factors that impact philanthropic giving by university alumni.	The findings demonstrate the importance of using segmentation and targeting approach for identifying and engaging with alumni to maximize alumni giving.
Marketing Mix (4Ps: price, product, promotion, and place)				
Artur, 2015	100 school marketing managers	Qualitative: online survey	Explores and seeks to gain an understanding of the role and importance of the Internet in the marketing activity of higher education institutions in Poland.	The Internet is a crucial element of the marketing activity of universities in Poland; however, the utilization of the Internet by universities has not kept up-to-date with the rapid developments in Internet technology.
Enache, 2011	All universities in Romania	Quantitative: Secondary data analysis of enrolled students	The 7Ps[a] framework is applied to gain a better understanding of the Romanian higher education market.	Applying the 7Ps[a] model from services marketing provides a useful framework for understanding, analysing, and managing the market forces that affect the higher education market.

Moogan, 2011	318 applicants 4 managers	Qualitative and Quantitative: survey questionnaire; in-depth interviews	The study was designed to identify the key marketing communications activities needed to meet students' needs when applying to university to inform university marketing managers.	The study found that while marketing communications, particularly program information, was readily available for students, more online resources would be welcome by undergraduate applicants.
Relationship Marketing				
de Macedo Bergamo et al., 2012	352 Brazilian students	Quantitative: survey; multiple linear regression	The study examines and tests the association between relationship quality and loyalty to an institution.	The strongest contributing variable to student customer loyalty is the perceived quality of the institution. Trust and commitment also positively influence student customer loyalty.
Iskhakova et al., 2017	N/A	Conceptual	The theory and perspectives used in studies of alumni loyalty and the constructs, measurement and scales used in the studies.	The results reveal that alumni research is conducted within a number of research areas including services marketing, education science; relationship marketing; management, charitable giving and microeconomics.
Kim et al., 2010	302 respondents from 3 Korean universities	Quantitative: survey (structural equation modeling)	Examines students' identification with their university to measure belongingness and satisfaction.	Students' strong identification with their sports program is positively related to their strong identification with the university as a whole and leads to a sense of belongingness & support for the university.
Purgailis & Zaksa, 2012	2010 university students (Latvia)	Quantitative: survey (structural equation modeling).	Examined the relationship between service quality and student loyalty to the HEI (University of Latvia).	Student-perceived quality comprises academic staff, study content, readiness for labor market, and acquired skills, which positively influence student loyalty to the HEI.
Schlesinger et al., 2017	1000 university alumni (Spain)	Quantitative: survey (structural equation modeling)	The study examines the role of brand image, trust, satisfaction, and shared values as a direct and indirect explanation of alumni loyalty.	The findings show that university image plays a key role, and four variables determine student loyalty: graduate satisfaction, trust, shared values, and image.

Source: The authors.

[a]The 7Ps are the 7 elements of the marketing mix (price, promotion, product, place (4Ps) plus: people, process, physical evidence (3Ps).

Appendix 5 Summary of articles on recruitment, alumni, and gift-giving for the literature review

Authors, date	Sample	Method	Summary	Results
Recruitment, alumni and gift-giving (excluding choice and consumer behavior)				
Asaad et al., 2015	63 international managers in UK universities	Quantitative: survey (Partial least squares analysis)	Aims to investigate export market orientation (EMO) in the context of British universities when recruiting international students	Concludes that four higher education export-specific variables are important drivers of EMO in universities. Also confirms the direct effects of EMO on university export performance and (indirect effects) mediated through international reputation.
Frølich et al., 2009	University admissions data (Norway); recruitment managers	Qualitative and quantitative: Secondary data on HEIs in Norway; 10 interviews	Explores the recruitment strategies of HEIs and examines how these strategies are linked to their market position.	The findings indicate that all universities in the study focused on the traditional market where they faced competition from other institutions. Institutions tended not to capitalize on their uniqueness in the market.
Hulme et al., 2014	N/A	Conceptual paper	The study focuses on international recruitment agents and questions, how agents justify their value, why universities are employing agents, and how potential students view agents.	The authors reveal contradictions in the stated aims of international recruitment via agents and the focus is on widening participation and offering opportunities; in reality, they reveal a market- and profit-driven system.
Onk & Joseph, 2017	Top 10 world economies	Qualitative and quantitative: Secondary data analysis	The study focuses on what emerging universities can learn from the strategies employed by established universities regarding student recruitment.	Priorities for successful international recruitment are: identifying sources of funding, setting up an international office, recruitment team, and recruitment process.
Pippert et al., 2013	10,000 images, 165 institutions (USA)	Qualitative: Content analysis (photographic images)	The study focuses on the way ethnic minorities and racial groups are portrayed in university recruitment materials.	Images were presented showing over-representation of African-American students: these students were over-represented in institutions' materials.

Alumni and gift-giving				
Alnawas & Phillips, 2015	22 alumni from 6 UK universities; 10 pilot respondents	Qualitative and quantitative: in-depth interviews; pilot study to develop a measurement scale.	To conceptualize and examine the concept of Alumni Orientation (AO) using a discovery-oriented approach. A self-administrated survey to validate the six identified constructs that form AO.	Confirms 48 item measurement instrument for AO is valid and reliable using nine multi-item components: Case for Support; Alumni Database Management; Social Media Management; Financing Event Management; Financing Publication Management; Promoting Best Practices of Event Management; Promoting Best Practices of Publication Management; Intra-functional Coordination; and Inter-functional Coordination.
Pedro et al., 2018	2544 alumni (Portugal)	Quantitative: survey (structural equation modeling)	To explore the satisfaction, image, and commitment of university alumni.	The findings indicate that communication and satisfaction with the social and academic environment at their university contribute to a positive alumni commitment relationship.
Stephenson & Bell, 2014)	2852 alumni (USA)	Quantitative: survey (negative binomial regression)	The study focuses on university brand identification and the willingness to make alumni donations.	Findings indicate that motivation for alumni donating is explained by using social identity theory.
Stephenson & Yerger, 2015	2763 alumni (USA)	Quantitative: survey (multiple regression)	The study examines the relationship between alumni satisfaction, brand identification, university brand image, promotion of the institution and choosing to donate.	Findings show that alumni satisfaction with student affairs and satisfaction with campus resources positively affect brand identification and brand image.

Source: The authors

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Chapter 3
Overview of Simulation in Higher Education: Methods and Applications

Efrat Tiram and Zilla Sinuany-Stern

Abstract Simulation is one of the most widely used methodologies in many areas such as industry, army, leisure activities, and education. This chapter is devoted to simulation in higher education (HE) and its use for administrative and educational purposes. Many types of simulation models have been used in HE for various purposes. Literature reviews have been published on specific types of simulations in HE but, to the best of our knowledge, there has not been a comprehensive overview of all types of simulation models in HE. We classify simulation models in HE into two types: (a) *analytic simulations* models such as discrete event simulation and system dynamics, and (b) *educational simulation* models such as, virtual reality, games, and simulators for training. This overview presents examples for each method, which gives some idea of the specific areas of HE they were used for. Moreover, taxonomy tables summarize the number of articles published over the last 20 years for each simulation method in HE in the Web of Science, along with the *area of applications* they are used for in HE. The number of articles on *educational simulations* is larger by far than the number of articles on *analytic simulations*. This overview is useful for developers of HE simulations and for administrators in HE institutions.

Keywords Higher education · Simulation · System dynamics · Discrete-event simulation · Agent-based simulation · Educational simulation · Simulator · Educational game · Virtual learning

E. Tiram (✉)
Sackler Faculty of Medicine, Tel Aviv University, Ramat Aviv, Tel Aviv, Israel

Z. Sinuany-Stern
Department of Industrial Engineering and Management, Ben Gurion University of the Negev, Beer Sheva, Israel
e-mail: zilla@bgu.ac.il

Z. Sinuany-Stern (ed.), *Handbook of Operations Research and Management Science in Higher Education*, International Series in Operations Research & Management Science 309, https://doi.org/10.1007/978-3-030-74051-1_3

3.1 Introduction

Simulation is a model which imitates a system or a process behavior to learn about the system over time (Yang, 2014). Simulation is used in many areas such as industry, business, military, engineering, city planning, medicine, leisure activities, and education. Banks (2009) defines “modeling and simulation” as an academic discipline with its own research methodology. Ideally, simulation has several steps, the first of which is building a model that approximates a real-world event. Such a model, which is usually computerized, often includes its own dynamics and involves repetitions and data collection. This step is followed by the analysis of the data and the drawing of conclusions (often with visualization). Ideally, the final steps are verification and validation of the model. This chapter is devoted to simulation in higher education (HE) and its use for administrative and educational purposes.

Simulation is a multidisciplinary method that advances technology. In 1999, the NSF officially declared simulation as the third branch of science (ibid., p. 3). There are many general simulation journals (e.g., *Journal of Simulation*), in addition to those focused on specific disciplines (e.g., *Simulation in Healthcare*, Simulation, and International Journal of Simulation Modeling) or on a specific sub methodology (e.g., *Simulation and Gaming*). Moreover, several disciplines (e.g., operations research, computer science, and industrial engineering) include simulation as a subdiscipline, some even offering a required course in simulation in their academic program either on how to build or apply a simulation model. Others just use simulation models for educational training (e.g., simulators and games). Almost all disciplines (and often subdisciplines) in HE have their own types of simulation models, including the following: games in business studies (Rosa et al., 2017), virtual reality in surgeon training (Papanikolaou et al., 2019), simulation-based learning using manikins in nursing education (Cant & Cooper, 2017), simulation in engineering education (Deshpande & Huang, 2011), and even dynamic simulation games for university management (Barlas & Diker, 2000).

Simulation is one of the most popular methods in HE. During the last 20 years, simulation appeared in the *topic* (article’s *title* or *abstract* or *keywords*) of over 1.8 million articles in Web of Science (WoS)—of them, about 100,000 articles were devoted to HE. Simulations can be digital or mathematical or both, physical versus virtual, visual versus interactive, static versus dynamic, web-based versus local simulator, digital game vs. role-playing game. Simulation models are usually computerized; the development of most simulation models was in tandem with the development of the computer and other technological platforms. During the last 10 years, smart phone simulation applications have become popular along with educational gaming, internet-based simulations, and, more recently, the cloud platform for simulation with big data (see the forthcoming special issue of the *Journal of Simulation* devoted to “Modeling and Simulation in the Cloud Computing Era”). Simulation is merely a proxy for a real system; it cannot capture the full capacity of the real system due to the latter’s complexity and the lack of information available about the real system. Thus, verification and validation are important. Sometimes the term *simulation* is used loosely in various contexts that are hard to define.

There are review articles on specific simulation methods in HE, as shown in Table 3.2, but no overview of all types of simulation models in HE is found in the scientific literature, to the best of our knowledge. The purpose of this chapter is to remedy this lacuna. The purpose of our study is to classify and present the various types of simulation methods as related to HE and to describe their areas of application and their frequency in the literature.

The closest to our classification is Banks (2009), with the introductory chapter to the book by Sokolowski and Banks (2009) that tries to present an overview on “Principles of Modeling and Simulation: A Multidisciplinary Approach” (ibid.). The article by Banks (2009) is on simulation models in general, not necessarily on HE, and is directed at graduate students, who have an analytic background, to be trained as builders of models and simulation. In contrast, our chapter is directed at HE management and researchers who do not have an analytic orientation. Banks (2009) classifies modeling and simulation into two types: (1) *Stand-alone simulations.* These are grouped into five categories: training, decision support, understanding, education and learning, and entertainment. (2) *Integrated simulation.* The criterion for this classification is “whether or not the simulation program runs independently from the system it represents” (ibid.).

The approach to classification in our overview is somewhat different. We first classify the various simulation methods and their areas of applications in HE; second, we give examples of articles on these methods in HE; and third, we count the frequency of appearance of the various simulation methods in the scientific literature in the context of HE.

We identify, in this overview, two main types of simulation models in HE:

1. ***Analytic simulations*** are subdivided into several methods: *(a) System dynamics, (b) Discrete-event simulation and Monte Carlo, (c) Agent-based simulation, (d) Deterministic simulation.*
2. ***Educational simulations*** are subdivided into several methods*: (a) Virtual, (b) Games, (c) Simulators, (d) Box trainer, (e) Manikins.*

Analytic simulations models (Yang, 2014) consist of mathematical equations or a series of relations between various components, be they deterministic vs. stochastic, discrete vs. continuous, or static vs. dynamic. An analytic simulation model in HE usually allows management to plan their affairs, to conduct virtual experiments, or to test policies and system behavior under various scenarios—answering “what if” questions regarding enrollments, income, costs, etc. (e.g., Zaini et al., 2017). Evidently, *educational simulations* in HE are much more popular than *analytic simulation* models and tools (Vlachopoulos & Makri, 2017).

This is not a comprehensive review of all simulation publications in HE, since there are too many such articles. Thus, this review provides a wide range of simulation methods applied in HE, classified by type, with examples that give some idea of the specific areas of HE they are used for and the level of HE hierarchy to which they are applied. Articles of literature review for specific simulation methods or areas of application are reported wherever possible. The examples are taken mainly from journal papers, mostly from the last two decades (from Google scholar). Moreover, taxonomy tables summarize the number of articles published for each simulation method in HE in WoS and the areas of applications they are used for in HE.

This overview is useful for administrators in HE institutions, including heads of departments, deans, consultants, and presidents, to apprise them of the growing use of simulations in HE and the advantages and disadvantages of their potential use in HE.

Section 3.2 of this chapter is devoted to *analytic simulation* methods in HE. Following that, Sect. 3.3 covers the main *educational simulation* methods. Section 3.4 provides the number of articles on simulation methods in each of these two groups and their areas of application in HE during 2000–2019. Finally, Sect. 3.5 concludes the chapter.

3.2 Analytic Simulations for Managerial Planning in HE

Analytic simulation models consist of mathematical equations or series of logical relations between various components, be they deterministic vs. stochastic, static vs. dynamic. Analytic simulation models in HE allow management to plan their affairs, to conduct virtual experiments, or to test policies and system behavior under various scenarios—answering "what if" questions regarding enrollments, income, costs, etc. In the Encyclopedia of Business Analytics and Optimization, Yang (2014) categorizes analytic simulation models into three types: system dynamics, discreet event simulation, and agent-based simulation or model. Brailsford et al. (2019) also used the same three simulation models in the context of operations research. These three models are digital models with commercial software—for example, AnyLogic supports all three models (ibid.) and simulation in R (Hallgren, 2013). We also added here subcategory Monte Carlo simulations which often appear with stochastic simulations as discrete-event simulation or agent-based simulation. Historically, the term simulation had been used loosely in the context of HE planning; thus, a fourth category can be devoted to those various mathematical deterministic static analytic simulations. In this section, the analytic simulation methods are presented:

(a) System dynamic (SD)
(b) Discrete-event simulation (DES) and Monte Carlo
(c) Agent-based simulation or model (ABS or ABM)
(d) Deterministic and other Analytic Simulation Models

As summarized in Appendix 2, in HE, all these simulation methodologies were used by management, mainly for planning in all the levels of HE: department, college, university, national, and international. There are other ways of classifying these analytic simulations such as, stochastic (Monte Carlo) versus deterministic simulation and discrete time versus continuous simulation. However, the classification we used here is the most common. In addition to the type of model, our taxonomy includes the area of application in HE, the level of the organization where the model was used, and the country of application (wherever relevant). We tried to cover a large variety of countries. In HE, all these three simulation methods were used by management mainly for planning efficiency and quality evaluation, strategy, forecasting, and resource allocation, as detailed in Appendix 2, which is organized in chronological order of the articles. The four analytic simulations are described in the following four subsections.

3.2.1 System Dynamic (SD)

SD was developed originally for industrial applications—termed originally *Industrial Dynamics* by its initiator, Forrester (1961). SD is based on a set of differential equations describing the relevant system as based on stock, flow, and feedback in each subsystem and the relationships among them. This is a deterministic continuous-time system, where rather than individual entities, a continuous flow of entities is moving in the subsystems. SD model consists of a set of differential equations which represent non-linear systems. An example of a computer package is STELLA (Richmond, 2004). STELLA is short for Systems Thinking, Experimental Learning Laboratory with Animation [also marketed as iThink since 1986]. The advantage of SD is that it is a non-linear model, which describes the interrelationships among various subsystems within a large system which are captured dynamically over time.

Already in Thompson, 1970, Thompson suggested the use of Industrial Dynamic simulation, where the model conceptualizes the HE institution as a system of interacting flows of students, faculty, capital assets, information, and money—the flows are continuous over time. By the late 1980s, White (1987) reported that Simulation is one of the most reported OR methodologies used in HE—third in frequency, with 24 out of 146 articles. However, White states that *"many of the large-scale simulation models for financial planning have fallen into disuse."* Nevertheless, 15 years later, Bell et al. (2012) highlighted SD as the most useful hardcore OR methodology used in HE. Thus, in their book, they devoted two chapters to SD approaches (chapter 11 by Galbraith, 2012; and chapter 8 by Voyer et al., 2012) while none to other types of simulation. Kennedy (2008) performed a taxonomy of SD educational policy. Later, Kennedy (2011) reviewed forty SD papers on HE (two more in K-12 education) and produced a taxonomy of SD models of educational pedagogic issues that were published during the period 2000–2010. His taxonomy was performed along two dimensions: five "hierarchical levels," and seven "areas of concern" in HE. In the hierarchical HE level dimension, most of the papers were devoted to university wide management issues. In the largest group in the "areas of concern" the papers were devoted to planning, resourcing, and budgeting. We identify in a WoS search that 2432 SD articles are applied to HE; namely, HE and SD appear in their topic (title or abstract or keywords), of which for 99 articles HE and SD appeared the articles' title. Here are some examples of applications of SD in HE, as summarized in Appendix 2 in chronological order.

Voyer et al. (2012) used the SD approach to improve an advising system for Business School undergraduates in the USA. Based on a survey of graduating seniors, advising services received low marks. With the school team, four key variables were identified for the main four subgroups: Advisors (total workload, advising workload, time spent with students, etc.); students (wait time, queue length, student satisfaction, etc.); faculty (faculty involvement, the complexity of curriculum, and guidance requirements; other (time frame, automated advising, and budget). The relationships among the key variables were verified to construct SD flowcharts which considered possible external disturbances outside of the Business School. Various policies were tested, and policy recommendations were presented to the management to improve the student advising system: increasing their satisfaction via using automation, simplifying the curriculum, and involving faculty in the advising process in critical periods.

Brailsford and De Silva (2015) used an SD model to plan the better provision of state-funded dental care and the future university intake of dental students in Sri Lanka. The model had two components—the supply and demand for dental services on the national level. The supply component considered the career progression of dentists from recruitment and training at the university through various career paths through retirement via SD. The demand component calculated various scenarios for the national future dental care, based on the potential future economic development of Sri Lanka.

Kara (2015) used a simple SD nonlinear stochastic model for the provision of HE service in Turkey on the national level during a global economic crisis. Two main assumptions were used: the quality performance was rising stochastically but modestly, and the increase in the technology level leads to improved employment perception and higher levels of employment. The demand and supply nonlinear time-dependent equations are estimated (via regression) as a function of HE price, customers' income, service quality, the degree of using technology in HE and expected job placement. The author presents the SD differential equations and the fluctuations of the main two variables over time as a function of the explanatory variables and the budget allocation to HE.

Fateh Rad et al. (2015) investigated the relationship between university and industry in Iran as two major infrastructures of national innovation systems in leading scientific and industrial settings. The relationship between the two systems is captured by SD nonlinear differential equations, based on a joint investment between industry and university, in three levels of communication from the lower to the higher levels.

Strauss and Borenstein (2015) developed their SD model for long-term planning of undergraduate education in Brazil at an aggregate level. As the purpose of the government was to increase undergraduate enrollment, it met with partial success. The scenario analysis considered government regulations/policies, demand, and the balance between the public and private sector.

Dandagi et al. (2016) used a questionnaire with 207 responses to establish causal relationships between factors for strategically governing a technical university in India. Factor analysis was used to generate latent variables, which were utilized to build the structural equations of SD model, for strategic management of the university.

Al Hallak et al. (2017) used SD for student enrollment in the Syrian private HE sector, which examined the dynamic interactions of student flows, staff ratios, and investments in facilities. This was a decision support system that might help to increase enrollments. Various scenarios were examined.

Faham et al. (2017) analyzed the key factors and obstacles related to education for sustainable development in HE. They created a model using SD to develop education for sustainable development in HE, with the emphasis on sustainability competencies of students. The approach of SD helped to recognize the interventional procedures in fostering competencies of students in the university. The model described the dynamic interactions among the students, scientists, content, policy, pedagogy, community, and government. The model was applied to the University of Tehran, Iran.

Ghaffarzadegan et al. (2017) used SD to model the education workforce pipeline on the national level. They introduced two mechanisms that act on the education enterprise, causing the number of educated people to increase dramatically with relatively short-term changes in the job market. Their illustrative dynamic model showed that the system was susceptible to small changes, and they introduced self-driving growth engines that were adequate to over-incentivize degree attainment. Moreover, they showed that the mechanisms magnified the effects of short-term recessions or technological changes and created long-term waves of mismatch between workforce and jobs. The implication of the theory was that degree inflation magnified pressures on those with lower degrees, and increased under-employment, job market mismatch, and inefficiency.

Zaini et al. (2017) reported on a real-life study in a USA university. In response to financial problems, the administration reduced undergraduate tuition, which resulted in an increase in student enrollment. The faculty, who argued that the quality of education had been declining, resisted the expansion. The growth in the number of students also affected the use of the university's infrastructure. The authors developed a simple SD model of university expansion with emphasis on the areas of planning, resourcing, and budgeting.

Kara (2018) was concerned with the mediocre, low productivity, and low-performance levels of many universities in developing countries. He suggested an SD model, where university performance was expressed by teaching quality, and research productivity levels were related to three resources: human capital, social capital, and physical capital. He used structural equations expressing the dynamic behavior of the system over time. The model measured the improvement in quality and productivity of the university as a function of subsidy and reinvestment. The simulation experiments obviated the need for the university to undergo a long and expensive trial and error process.

As shown in Table 3.1, in our search of WoS during 2000–2019, *SD*, in general, appeared in the *topic (*title, abstract, or keywords) of 37,763 articles; the combination *system dynamic and HE* appeared in the *topic* of 2432 articles, and *system dynamic and HE* appeared in the *title* of 99 articles.

Table 3.1 Number of articles on *simulation methods* in general and in higher education[a]

Method Name	Number of articles during 2000–2019			Percentage	
	1. Method in topic	2. Method and HE in topic	3. Method and HE in title	Column (2) from (1)	Column (3) from (1)
1. Simulation	1,834,848	99,026	4223	5.397	0.230
A. Analytic simulations					
2. System dynamic (SD)	37,763	2432	99	6.440	0.262
3. Monte Carlo	225,568	8851	176	3.924	0.078
4. Discrete-event (DES)	69,259	5426	129	7.834	0.186
5.a Agent-based (ABS)	48,772	3502	171	7.180	0.351
5.b Deterministic and others	407	34	0	8.354	0
A. Total of Analytic Sim.	**381,769**	**20,245**	**575**	**5.303**	**0.151**
B. Education simulations					
6. Virtual	261,559	30,390	2650	11.619	1.013
7. Simulator	102,142	9583	449	9.382	0.440
8. Game	188,519	14,878	1447	7.892	0.768
9. Box trainer	316	126	3	39.873	0.949
10. Manikin	3516	963	41	27.389	1.166
Total of Education Sim.	**556,052**	**55,940**	**4590**	**10.060**	**0.825**
Total A + B	**937,821**	**76,185**	**5165**	**8.12**	**0.551**

[a]Assessed from the Web of Science, Oct. 2020. See Appendix 1 on synonyms for HE and each simulation method. Topic includes title, abstract, or keywords. Bold lines are the totals of the groups of simulation methods

3.2.2 Discrete-Event-Simulation (DES) and Monte Carlo

Discrete-event simulation (DES) first emerged in the late 1950s and steadily grew in popularity to become the most frequently used of the classical Operational Research techniques across a range of industries and users. DES models look at the operation of a system as a discrete sequence of events in time, typical of a manufacturing process. Each event occurs at a particular instant in time and marks a change of state in the system. This contrasts with continuous simulation, in which the simulation continuously tracks the system dynamics over time. Conventional DES constructs are entities, activities, and queues; these constructs are linked to form a complex process in which entities flow. Probability functions are also used to model stochastic processes. DES, alternatively termed Activity-Based Simulation or Monte Carlo Simulation (Banks et al., 2005), is the main analytic simulation model used in practice since the 1960s. In DES, the incoming entities stand in queues, and they receive service activities or resources in a station. In some systems, human service becomes part of the activities and resources. DES allows for the randomness of the service time of the service provider within a given probability distribution and randomness of the inter-arrival time between entities all within given probability distributions. The following are some examples of the application of DES in HE.

Schellekens et al. (2010) developed a process-focused, demand-driven operational model for delivering educational programs to support the development of individual students and to provide a flexible alternative for the traditional supply-driven and class-based organization of educational programs. DES was developed and applied to the higher education of professionals in the Netherlands.

Oltean et al. (2017) dealt with facility planning and renovation using DES. The purpose of DES was the viability of the building and maintaining process in a generic public university organization. The events were driven by internal, external, or mixed causes generated randomly. Some of the uncontrollable events occurring in the process may drive the discrete evolution to disturbance rejection states, where specific recovery strategies are applied. If recovery is successful, disturbances may become sources of innovation.

As shown in Table 3.1, in our search of WoS during 2000–2019, *discrete-event*, in general, appeared in the *topic* (title, abstract, or keywords) of 69,259 articles; the combination *discrete-event and HE* appeared in the topic of 5426 articles; *discrete-event and HE* appeared in the *titles* 129 times.

Since most models of DES and ABS are stochastic, using randomness, where the randomness often materializes via sampling like Monte Carlo gambling. Often Monte Carlo appears together with DES and sometimes also with ABS. Thus, it appears in the literature more than DES and ABS combined. Referring to Table 3.1, in our search of WoS during 2000–2019, *Monte Carlo*, in general, appeared in the *topic* (title, abstract, or keywords) of 225,568 articles; the combination *Monte Carlo and HE* appeared in the topic of 8851 articles; *Monte Carlo and HE* appeared in the *titles* of 176 articles. However, the count in the title of the articles shows that *Monte Carlo* is even less than ABS. Monte Carlo simulation without DES or ABS stands for various other analytic stochastic simulation methods.

3.2.3 Agent-Based Simulation (ABS)

Agent-based Simulation (ABS) is a relatively new paradigm that simulates the simultaneous operations and interactions of multiple autonomous agents (determine their own actions) to predict complex processes. The agents can be individuals, groups, or institutions. Agents may behave differently from each other. ABS assesses agents' effects on the system as a whole—it adds behavior (in terms of decision rules) to micro-simulation. Agents' behavior can be adaptive in response to other agents or environmental changes or other agents' behavior; feedback and memory are crucial in ABS. Monte Carlo is utilized to generate randomness. ABS has elements of game theory, complex systems, and multi-agent systems (Yang, 2014). Siebers et al. (2010), who reviewed DES in general (not necessarily in the context of HE), claimed that DES is "dead" while ABS, which replaces it, will stay for a longer period. They state that in the early 1990s, ABS "promised to offer something novel, interesting, and potentially highly applicable to OR. However, there is relatively little evidence that ABS is much used in the OR community, there being few publications relating to its use in OR and OR-related simulation journals." Indeed, ABS is a more general model than DES, and thus it is more complicated, requiring more data. This makes it more difficult to use, especially in the case of HE administrators. Moreover, not every situation requires ABS, and a basic course in simulation is not likely to include ABS—it is dependent on the instructor and the software chosen for the course. Nevertheless, OR specialists have been using ABS without using this term since the late 1980s. See, for example, Stern and Sinuany-Stern (1989), Sinuany-Stern and Stern (1993), and Sinuany-Stern et al. (1997), where the terms used were behavioral based in DES, within the framework of operations research.

In the literature review of ABS by Gu and Blackmore (2015), they see ABS as a bottom-up model where the macro-level behavior is a result of the micro-level agents and their interactions. In their systematic review of the applications of ABS in HE by area of application, they present thirty-five articles during the period 1997–2013. During the years 1997–2005, the number of articles published was one or none every year. The areas with the maximal number of articles were academic activities (with twelve articles) and teaching and learning (ten articles). Three more areas with four articles each were: student performance, application and enrollment, and university collaboration. They also found ABS applications in the ranking of universities.

Molders et al. (2011) suggested modeling scientists as agents. Base on this idea, Gu et al. (2015) built a hypothetical ABS, where the productivity of the agents (scientists) is measured under several environmental assumptions. Three types of academic agents (scientists) were categorized by their strategy: Careerists who strive for high IF journals, Orthodox who strive for topical fitting factor, and Mass who strive for high acceptance rate journals. The papers are characterized by impact factor, acceptance rate, and topical fitting factor. The simulation has six sub models: (1) Create journal, (2) Create academics, (3) Academics move around, (4) Academics submit papers, (5) Journals publish papers, (6) Retire and recruit academics. The number of journals and total number of acceptable papers stayed the same in all scenarios. This was a competitive environment where the composition of each group of academics changed over the scenarios. The results showed that the Orthodox type has the most consistent achievements.

Tan et al. (2019) built a discrete-timed stochastic simulation model based on parallel systems to explore the relation between the number of submissions and the overall standard of academic journals within a similar discipline under peer review. The model simulates the submission, review, and acceptance behaviors of academic journals in a distributed manner. The results point to the possibility that the standard of academic journals deteriorates due to excessive submissions. Over twelve articles are cited on this issue using ABS, including a review of the literature on the use of ABS in scientific publication and the peer-review system by Kovanis et al. (2016).

As shown in Table 3.1, in our search of WoS during 2000–2019, *agent-based*, in general, appeared in the *topic* (title, abstract, or keywords) of 48,772 articles; the combination *agent-based and HE* appeared in the *topic* of 3502 articles; *agent-based and HE* appeared in the *titles* of 171 articles.

3.2.4 Deterministic and Other Analytic Simulation Models

Already in 1967, Weathersby applied a linear regression simulation model to predict costs of academic departments in the University of California, Berkeley. Cost simulation is defined as a collection of mathematical expressions that attempt to interrelate analytically; these are the costs and input parameters of HE institutions. Hopkins (1971) called such mathematical models deterministic simulation models. Some of them are large scale for university planning. Hopkins raised questions about their large expense and accuracy. Often the models are not well understood by HE administrators, and they require major data collection. Sinuany-Stern (1983) illustrated the general structure of a cost simulation model for university planning (Fig. 2 and Fig. 4; p. 212, 214, ibid.) utilizing a set of equations where some led to others.

Larson et al. (2014) claim that there were too many PhD graduates, i.e., too few academic job openings. They used a demographic model, utilizing a basic reproductive number R_0—the mean number of new PhDs that a typical tenure-track faculty member will advise during his career. The model calculated that in the then current situation, $R_0 = 1$ was sufficient to secure tenure track positions for all PhD graduates, but in a situation of regional population growth, a higher value was needed $R_0 > 1$. Applying the model to MIT data in 2011, the R_0 average in engineering was 7.8, which was too high. Some fields had a reproductive value $R_0 < 1$, which indicated a severe shortage of PhDs in the future (e.g., mechanical engineering). However, another field had $R_0 = 19$ (environmental engineering). The authors suggested that the intake of PhD students by disciplines could be improved by also considering the industry demand for PhDs in areas such as STEM and by raising the level of master's degree graduates, which may replace the access demand for PhDs by industry.

Siniksaran and Satman (2020) designed a simulation software, "World Universities Ranking Simulator" (WURS), for the three popular world university rankings: THE, QS, and ARWU. The purpose of the simulator was to enable the institution to detect the parameters they need to improve in order to raise their scores in these three rankings. The data needed was outlined, and the transformations and manipulations performed by the simulator were detailed.

3.2.5 Combining Analytic Simulation with OR and Other Methods

Simulation is one of the most popular methods in HE and in operations research in general. Yang (2014) stated about analytic simulation methods (i.e., SD, DES, and ABS): "In OR context, simulation is often used as part of business optimization to understand the impact of changes" and is used sometimes to improve the system. As a future direction, Brailsford et al. (2019), in their general review of simulation, suggested using a hybrid of some of the above-listed simulation methods with each other and with other OR methodologies, such as optimization. They pointed at AnyLogic software as the most used simulation software, which accommodates the three types of analytic digital simulations: SD, DES, and ABS.

Below are some HE applications which combine simulation with other OR methods.

Barlas and Diker (2000) developed an interactive dynamic simulation model into a university management game, UNIGMAE, based on SD. They generated numerous performance measures and demonstrated the systemic nature of university management. This game enabled stakeholders to understand those individual decisions, in isolation, yield counterintuitive results when not coordinated with related decisions. Sinuany-Stern (1978) combined deterministic simulation for cost prediction with optimization for budget planning in a multi-campus community college.

Hussein and El-Nasr (2013) used SD simulation to understand the relationships among various design factors of an HE quality model. The TQM (total quality management) approach was used, where eleven main factors affecting quality were identified: building, facilities, courses, marketing, counseling, library and information centers, student services, legalism and morals, scientific evaluation, staff level, and management. The institutional budget can be allocated proportionally to the weights given to each factor by management. However, an optimization model utilizing a *genetic algorithm* was suggested to achieve an optimal budget allocation of the SD model to maximize the quality of the HE institution. NetLogo software was used (https://ccl.northwestern.edu/netlogo/).

3.3 Educational Simulation in Higher Education (HE)

There are additional special types of simulations, educational simulations, specific to pedagogy in HE, which are used much more often than the analytic simulations mentioned in Sect. 3.2. These *educational simulations* include: serious games, video games, computerized and non-computerized simulators, physical simulators, virtual worlds, and massive multi-player online games—most are digital, internet bases, and computerized—and all are used for teaching and training in HE (Bradley, 2006). We classify *educational simulations* into five main methods:

1. Virtual
2. Simulator
3. Game
4. Box trainer
5. Manikin

"Simulation and gaming" sometimes is used as a general term for educational simulation. Simulation in the pedagogy of HE is spreading with the evolution of computer technologies and internet-based communications. These pedagogical tools and computer-based simulations, and serious games enrich the learning and practical training in many disciplines.

Since there are too many articles on *educational simulation* (4590 articles vs. 575 for analytic simulation, as shown in Table 3.1), Table 3.2 and our overview contain mainly review articles in this section, while covering these five methods. Sometimes the terminology of the five methods is fuzzy; thus we divided Sect. 3.3 into two main parts: Sect. 3.3.1 is devoted to the five educational simulation methods, while Sect. 3.3.2 is classified by academic disciplines.

3.3.1 Educational Simulation by Method

3.3.1.1 Virtual Learning

Virtual simulation enables 3-dimensional environments and objects to look real when transmitted, which creates for the student an immersive and engaging learning experience. A virtual Lab allows the student to perform experiments virtually, saving materials, reducing cost, increasing safety, and enhancing accessibility, especially in STEM disciplines. Virtual simulations are often used for training in various medical fields such as nursing, surgery, radiotherapy, midwife training, radiation therapy, and pharmacy education. The main advantage of using virtual simulations is the ability of the trainees to repeat the procedure tasks several times. For instance, in the field of surgery, the possibility to repeat a certain surgical procedure enhances the muscle memory ability by internalizing effective feedback within its virtual platform (Papanikolaou et al., 2019). For example, the Moog Simodont dental trainer is Virtual reality (VR) based platform which was introduced within the pre-clinical studies and was examined in a study within an operative density restoration course for undergraduate students (see Murbay et al., 2020). Manual and digital methods were included to evaluate the students' performance. It was found that the students who were exposed to the Moog Simodont were evaluated significantly higher with performance and preparation (manually and digitally). These findings support and strengthen the claim that this virtual reality simulator is essential to improve dentist student's skills and contributes to such kind of undergraduate restoration course (ibid.).

Table 3.2 Review of articles on educational simulation in higher education

Author (year)	HE area reviewed	Years covered	Type of simulation	No. of Articles reviewed	Type of review[a]
Faria et al. (2009)	Business	1970–2009	Business games	304	All[b]
McGaghie et al. (2010)	Simulation-based medical Edu. (SBME)	2003–2009	All medical simulations	64 selected articles	Compared to 3 reviews from 1969–2003
Cant and Cooper (2010)	Nurse education	1999–2009	Manikin	12	NSR
Deshpande and Huang (2011)	Engineering Edu.	1960–2006	Computer game simulation	70	SR
Kennedy (2011)	Pedagogic	1972–2008	System dynamic	40	SR
Cooper and Fox-Young (2012)	Midwifery Edu.	2000–2010	Actor, manikin and virtual	24	SR
Smithson et al. (2015)	Pharmacy	2000–2013	Standardized patient	27	SR
Warren et al. (2016)	Nurse Edu.	2007–2014	Manikin	10	SR
Doolen et al. (2016)	Nurse graduate Edu.	2009–2015	High-fidelity simulation	7 of 34 reviews	Umbrella SR
Sun et al. (2017)	Airway management Edu.	Until 2016	Virtual, comp. Software or manikin	17	SR meta-analysis
Adib-Hajbaghery and Sharifi (2017)	Nurse research Edu.	1975–2015	Manikin	16	SR
Vlachopoulos and Makri (2017)	Across academic fields	2010–2016	Game	123	SR
Cant and Cooper (2017)	Nurse Edu.	2010–2015	Manikin	25reviews	Umbrella SR
Rosa et al. (2017)	Business	1970–2016	Business game	157	SR
Frank et al. (2018)	Surgery arthroscopic	1999–2016	Simulator	57	SR meta-analysis
Horsley et al. (2018)	Nursing research interprofessional	2010–2016	Nursing simulation	48	SR
Kane (2018)	Radiation therapy Edu.	2000–2018	Virtual	40	NR
Papanikolaou et al. (2019)	Surgeons	Until 2018	Box trainer	50	NR comparative
Foronda et al. (2020)	Nursing education	1996–2018	Virtual simulation	80	SR

[a]SR—Systematic Review. NR—Narrative Review, NSR—Narrative Systematic Review
[b]The authors reviewed all articles of one journal "Simulation and Gaming" since its inception in 1970

As shown in Table 3.1, in our search of WoS during 2000–2019, *virtual* in general appeared in the *topic* (title, abstract, or keywords) of 261,559 articles; the combination *virtual* and *HE* appeared in the *topic* of 30,390 articles; *virtual and HE* appeared in the *titles* of 2650 articles.

3.3.1.2 Simulator

A simulator is a device that allows the person to train in an environment like the real one, such as a driving simulator (e.g., car or airplane) for training or practice driving under various conditions. Simulators are also used in medical training. For example, Frank et al. (2018) reviewed 57 articles on the use of arthroscopic simulators for training surgeons to perform joint surgery. In the first level, the improvement in diagnostic arthroscopic operation was noticeable within the simulator itself. In the next stage, a correlation was observed between basic diagnostic arthroscopy and standard of practice. Finally, limited findings indicate that when basic diagnostic arthroscopy procedure is applied in patients, as a continuation of simulator training, it is much more improved and successful (ibid.). The advantages of the simulator include increased safety for patients, a reduction in the time needed for "hands-on" learning by surgeons on the real system (patients in this case), and improvement in diagnostic capabilities.

As shown in Table 3.1, in our search of WoS during 2000–2019, *simulator*, in general, appeared in the *topic* (title, abstract, or keywords) of 102,142 articles; the combination *simulator* and *HE* appeared in the *topic* of 9583 articles, and simulator *and HE* appeared in the *titles* of 449 articles.

3.3.1.3 Games

A simulation game presents students with real-life scenarios relevant to their discipline. Usually, it is competitive, involves several players or groups of players, and is computerized. The game simulation provides the players (students) with rules, strategies, and chances of events to happen, all of which develop students' skills. Juan and Loch (2017) claimed that innovative, serious games and simulations in the pedagogy of HE are spreading with the evolution of computer technologies and internet-based communications. They stated that the use of games and simulation in HE is still in its early stage. Nevertheless, it is just a question of time until such games will gain widespread acceptance. They reviewed five articles that appear in a collection devoted to games and simulations in HE (ibid.). One of these articles is by Vlachopoulos and Makri (2017), who lump together the terms "game" and "simulation," listing the following types of games/simulations in HE: educational games, digital game-based learning, applied games, interactive exercises, and next-generation video and simulation games (games modeled after natural or man-made systems or phenomena, in which players must achieve pre-specified goals). The delivery of games and simulations can be via computer, web browser, consoles, mobile phones, and other mobile gaming devices. These games include serious games, as well as game-based learning in various academic disciplines. The learning goals of the game/simulation can include knowledge acquisition and understanding, increased motivation, engagement, and skill acquisition. The technique can be described as single/multi player, linear/nonlinear, collaborative, competitive, persuasive, synchronous, or immersive. They performed a systematic review of games and simulations in HE, reviewing 123 articles between 2010 and 2016. When the breakdown of the articles was by discipline, business/management led with 21 of the 123 articles; next was health sciences (16 articles), and then computer science (11 articles). Interestingly, 25 of the articles were devoted to Meta-Analysis and Systematic Reviews (ibid.). The results indicated that games and simulations were effective and had a positive impact on cognitive and behavioral learning goals. They concluded that the use of gamified mobile apps and virtual learning (e.g., a student game to practice a business negotiation) increased student engagement, retention, and academic achievements (ibid.).

As shown in Table 3.1, in our search of WoS during 2000–2019, *game*, in general, appeared in the *topic* (title, abstract, or keywords) of 188,519 articles; the combination *game and HE* appeared in the *topic* of 14,878 articles; the combination *game and HE* appeared in the *titles* of 1447 *articles*.

3.3.1.4 Box Trainer

Box trainer is a specific tool designed for laparoscopic surgery that replaces invasive surgeries, thus minimizing cuts of body tissues. Consequently, it is almost impossible for surgeons to have a 3-dimensional view of the operating area. This means more training is required for surgery students. The box trainer is a specific tool with three-dimensional graphics and the use of motion sensors for realistic movements (motion control) to simulate the real situation. Papanikolaou et al. (2019) published a narrative comparative review focused on box trainers and virtual reality simulators. Their review went up to 2018 and covered about fifty articles. Surgical training with box trainers conferred a significant benefit in terms of surgical skills development, increased patient safety, and overall cost reduction even though the use of virtual reality simulators was significantly more expensive. They concluded that simulation training allowed trainees to learn from their mistakes, to repeat surgical tasks multiple times, to establish muscle memory, and to enhance skill competency with the aid of informative feedback.

An example of laparoscopy box trainer type for training basic laparoscopy skills is a "Portable Ergo-Lap Simulator" (which was designed by Dong juan Xiao, within the industrial design engineering in Delft University of Technology, the Netherlands www.tudelft.nl/en/ide/research/research-labs/applied-labs/laparoscopy-box-trainer/). The main aim of this simulator is to help medical staff to improve their proficiency under ergonomic conditions, and its tasks are based on scientific research regarding laparoscopy necessary and relevant skills in this field, as well as feedback of sixty surgical participants after they carried out tasks on the prototype.

As shown in Table 3.1, in our search of WoS during 2000–2019, *box trainer*, in general, appeared in the *topic* (title, abstract, or keywords) of 316 articles; the combination *box trainer and HE* appeared in the *topic* of 126 articles; *game and HE* appeared in the *titles* of 3 articles.

3.3.1.5 Manikin

Manikin is an example of a physical simulator used in nursing education. The use of manikins is associated with reduced costs, increased efficiency in performing certain tasks, and above all, with safety. For example, Lapkin and Levett-Jones (2011) performed a cost-utility analysis to compare medium vs. high-fidelity human patient simulation manikins in nursing education. They used multi-attribute utility function and calculated the costs associated with each of the two alternatives. The conclusion was that medium-fidelity manikins are much more cost-effective than high-fidelity manikin with the ratio of 1:5.

Another study by Curran et al. (2015) examined a different approach to the differences between low and high-fidelity manikin simulators and was conducted within the neonatal resuscitation program (NRP). This program aimed to improve the skills of physicians and other health care staff regarding newborn resuscitation. Medical students participated in the study and were divided into two groups (low and high-fidelity manikin), and the following variables were examined: integrated skills, satisfaction, confidence, and teamwork. The findings raised that satisfaction and confidence were significantly higher in the high-fidelity manikin simulator group comparing to the low-fidelity manikin (yet no significant difference was found regarding integrated skills as well as teamwork).

As shown in Table 3.1, in our search of WoS during 2000–2019, *manikin*, in general, appeared in the *topic* (title, abstract, or keywords) of 3516 articles; the combination *manikin and HE* appeared in the *topic* of 963 articles; *manikin and HE* appeared in the *titles* of 41 articles.

3.3.2 Educational Simulation by Discipline

In this subsection, we cover some disciplines that use educational simulation. We concentrate here mainly on review articles of educational simulations.

3.3.2.1 Health Disciplines

Bradley (2006) wrote about the history of simulation in medical education and how simulation-based training became a standard for medical education. Simulation-based learning affords opportunities to address multiple domains of learning and performance. Unlike traditional clinical education, simulation-based learning provides learners exposure to events that are rare in the clinical setting too and allows learners to assume leadership roles in emergencies. In the health sciences context, simulation means a suitably analogous situation, using digital, virtual, simulator, or other physical apparatus for student/personnel training in many academic health disciplines. McGaghie et al. (2010) reviewed 64 selected articles on simulation-based medical education (SBME) from 2003–2009 and three review articles from 1969–2003. They discuss twelve features and best practices of SBME that teach the need to know to best utilize SBME, concluding that SBME is a complex service intervention that needs to be planned and practiced with attention to organizational contexts (ibid.). Below are some examples of several health disciplines.

Nursing Education: The main simulation tools in nursing education are those that represent patients, from manikins to virtual Lab. The major concern is the fidelity of this simulation, as Nehring and Lashley (2010) claim in the book they edited, containing twenty chapters by various authors, covering various aspects of high-fidelity in nursing education such as research, setting a patient simulation program, and creating an interdisciplinary simulation center. As shown in Table 3.2 there are many literature reviews on nursing simulations (Cant & Cooper, 2010; Cooper & Fox-Young, 2012; Warren et al. 2016; Horsley et al., 2018; and Foronda et al., 2020). Cant and Cooper (2010) reviewed twelve articles on simulation in nursing education (1999–2009), concluding that further exploration is needed to determine the effect of team size on learning and to develop a universal method of outcome measurement. Warren et al. (2016) reviewed ten articles (2007–2014) on the effectiveness of simulation-based education on satisfaction and learning outcomes in nurse practitioner programs, concluding that high fidelity simulation increases students' knowledge and confidence. Adib-Hajbaghery and Sharifi (2017) reviewed sixteen articles (1975–2015) about the effect of simulation training on the development of nurses' and nursing students' critical thinking, concluding that more studies with careful designs are needed to produce more credible evidence on the effectiveness of simulation on critical thinking.

Review of reviews (umbrella review) was performed by Doolen et al. (2016), who reviewed thirty-four review articles on high—fidelity simulation in undergraduate nursing education. They found that only seven articles met some inclusion criteria. They conclude that faculty do not receive enough support in using the simulation. Furthermore, there are great differences among the reviews and the studies, which limit the findings (ibid.). Cant and Cooper (2017) used also applied an umbrella review of twenty-five systematic reviews (2010–2015), covering 700 studies on simulation-based learning in undergraduate nurse education. They concluded that, although most reflect strong satisfaction with simulation education, there are still some gaps in comparable design of the reviews.

Eighty articles on virtual simulations (published during 1996–2018) were reviewed by Foronda et al. (2020) systematically via meta-analysis. They found that most of the articles (86%) pointed at the effectiveness of virtual simulation in nursing education. They conclude that there is a need to improve the research design (ibid.). Horsley et al. (2018) reviewed 48 articles (published during 2010–2016) on interprofessional health care teams in nursing education. Their findings show that collaborative health care in nurse education increased safety and quality of patients' care and satisfaction and reduced health care cost.

In HE, there is a crucial advantage for using virtual reality simulations to achieve improvement in practical skills. For example, to examine the process of medication administration, a study was performed to evaluate the effectiveness of Pharmacology Inter-Leaved Learning Virtual Reality (PILL-VR) simulation in nursing students versus traditional methods (see Dubovi et al., 2017). The students were divided into two groups: one learned with regular lecture-based curriculum, while the other used the platform of PILL-VR simulation platform. A higher significant achievement in knowledge learning (conceptual as well as procedural) were obtained in learning activities with the assistance of the PILL-VR simulation (ibid.).

Airway Management Education: Airway management is often life-saving procedure for patients in acute situations. Sun et al. (2017) reviewed seventeen articles (until 2016) on simulation in airway management education, using meta-analysis to compare simulation-based training for airway management (virtual, computer software, or manikin) versus non-simulation-based training methods. They recommended combining the two methods.

In the field of nursing, methods for training in difficult airway management are not common in study courses. A Virtual Reality (VR) airway intervention is presented and examined within a pilot study to teach difficult airway management (Samosorn et al., 2020). According to the findings, the VR airway Lab was rated high by students and faculty regarding different indices such as improving knowledge in the field of airway management.

Midwifery Education: Like the situation in nursing, patient simulation practices can be defined as the substitution of a bona fide patient encounter with artificial models or manikins, virtual reality, or live actors enacting a scenario that replicates substantial aspects of the real experience in a controlled, safe environment for midwifery.

Cooper and Fox-Young (2012) reviewed twenty-four articles (2000–2010) on simulation-based learning in midwife education, utilizing various simulation methods/tools (e.g., actors, manikin, virtual), concluding that simulated learning of midwifery skills is beneficial, though the clinical practice is still needed. Articles with evidence from obstetrics, neonatology, technical and non-technical skills (teamwork) were included.

A pilot evaluation was performed at the Queensland University by Downer et al. (2020). The use of 3D midwifery visualization resources (3DMVR) by midwifery students was evaluated. The traditional methods (such as books, lectures, and clinical skills in Lab sessions) were available to the midwifery students in addition to the 3D tool. The aim was to evaluate if the 3D tool enhances the students' conceptual understanding of the processes related to birth. According to the results, all midwifery students expressed that the 3D experience was beneficial. The participating students were satisfied with the tool and indicated that the experience allowed an improved and deep understanding of the anatomical and physiological aspects of the process.

Pharmacy Education: Smithson et al. (2015) reviewed twenty-seven articles on standardized patients in pharmacy education, concluding that gaps in knowledge around transferability, scalability, and cost benefit of this technique still exist, and there is a need for pharmacy educators to address these gaps to justify this resource-intensive teaching method. Virtual reality technology provides an immersive and interactive learning environment for pharmacy students as they provide service to patients. Coyne et al. (2019) provided an updated overview of virtual reality in pharmacy education.

Cheesman et al. reported on their experiment on the effective use of Virtual Laboratory Practical Class (VLPC). They took two groups of second-year pharmacology students. One group had access to the VLPC before their Lab session, and the second group had access to the VLPC after their Lab session. The results showed that the first group performed better—with a lower mean completion time compared to the second group. Moreover, the first group reported an increase in their confidence in successfully completing the live practical Lab experiment. They conclude that attending VLPC before the live practical Lab is more effective than attending VLPC after the live practical Lab.

Radiation Therapy Education: Kane (2018) wrote a systematic narrative review of about forty articles on simulation-based education, mainly in virtual environment radiation therapy (VERT) education during 2000–2018. He concludes that: "The evidence suggests that future inquiry involving VERT should explore different ways in which VERT can be used to contribute to the skillset required by the radiation therapist of tomorrow" (ibid.).

3.3.2.2 Simulations in Business Management

Vlachopoulos and Makri (2017), in their review of simulation and gaming in HE, in general, reported that out of 123 articles they reviewed, business management/marketing had the largest number of articles (21); the rest of the articles were devoted to various other disciplines.

Faria et al. (2009) wrote a review of the history of business gaming covering one specific journal, *Simulation and Gaming,* where 304 articles were devoted to some aspects of business games out of 1115 published in that journal during 1970–2009, representing 27.3% of *Simulation and Gaming* total publications. In HE, business games started in a university course in the USA (University of Washington, 1957). Since 1962, business games development stages were tied to computer development: first on mainframes and then growing in complexity until 1984, when PC-based games were developed. Since 1998 internet-based business games were introduced and used in HE. The five main topics that appeared in the literature of business games over the years were: experience gained, strategy aspects of the game, decision-making experience gained, learning outcomes provided, and teamwork experience provided by business games. Since the turn of the millennium, games focusing on specific areas were more common. Examples include games related to marketing, accounting, stock market and finance, and human resource management. Some of the games allowed the use of analytical tools such as forecasting.

For example, Rosa et al. (2017) performed a systematic review of 157 articles on business games during 1970–2016 to analyze the relationship between games and the development of creative potential in business games. They found that business games were not used specifically to promote creativity. Nevertheless, some other related themes were reviewed, such as cognitive and behavioral aspects (ibid.). Business games are often digital and involve several participants in a competitive situation. Sometimes the term gamification was used. Another example is Avramenko (2012) which referred to enhancing students' employability through business simulation.

Computerized Simulation Games for Software IT Project Management: Lui et al. (2015) designed an improved simulation game to train a group of students to take the role of project managers, where the objective was to complete a software design project on time, while adhering to the requirements of the stakeholders, and staying within a limited budget. The players were able to monitor the progress and the effects of their decisions. This design attempted to improve on various elements in other such games existing at the time.

3.3.2.3 STEM Disciplines

For STEM (science, technology, engineering, and mathematics), there are various types of simulations, specific for each discipline and dealing with education and/or research, and sometimes as developers of new simulations. The most frequent use of educational simulations for STEM education is for virtual laboratories.

Alkhaldi et al. (2016) reviewed eleven articles on the implementations of virtual and remote laboratories in various STEM disciplines. Among the Labs in this review Labs were those in physics, biology, chemistry, computer science, information technology, robotics, and mechanical engineering. The advantages of such Labs were summarized as follows: accessibility and flexibility from anywhere at any time, the ability to fit individual pace and schedule, the retrial of experiments without wasting resources, and safe environment. These simulation Labs were often online or cloud based. It was suggested that integrating physical Labs with virtual Labs in creative way would enrich learning.

Deshpande and Huang (2011) studied the state of the art of computer game simulation, where active multi-sensory experiential learning methodologies were used in engineering education. Their review covered the period 1960–2006 and included seventy articles. They reviewed simulation games applications in engineering education in the following eighteen engineering areas (and subareas): civil engineering, electrical engineering (including digital signal processing and power electronics), computer engineering (digital logic, security, protocols, software engineering, information systems, and artificial intelligence), chemical engineering, mechanical engineering (including Engineering, graphics, mechanics, thermodynamics and system dynamics), industrial engineering (including enterprise resource planning, production planning and control and supply chain management) and environmental engineering. In their table of simulation games, they refer to about seventy games in various areas, in addition to engineering, such as business, medical, health, architecture, and physics. They conclude that proper application of simulation games in engineering education would maximize the student's transferability of academic knowledge to industry.

Another example, in the field of developmental biology, a neurosphere simulator became into use during the limitations of the COVID-19 pandemic via online, because of movement from "face to face" Lab classes into an online teaching era (Zupanc et al., 2021). This simulator was developed based on cellular automata models of neurosphere growth and is freely available for students on the web (http://neurosphere.cos.northeastern.edu/). The simulator allows students to experiment with different components of the biological processes which were expressed in the computerized model during this Lab class exercise online, and to download data for further specific analysis, as well (ibid.).

City Planning education: Minnery and Searle (2013) presented an innovative way of using a toy computer game of a city (SimCity 4) in student assignments to develop urban and strategic plans.

In summary, the use of simulation and games in the pedagogy of HE has been growing over the years. For the most part, students were satisfied, though faculty support was sometimes insufficient. Cost effectiveness was usually justified, but not always reported. The literature review and umbrella systematic review articles in Table 3.2 reflect the great variability of the studies' purposes and designs, thus comparability is not always evident. The health educational simulations reported most often in the literature were manikins and virtual simulations. STEM educational simulations were mostly for virtual Labs, while business educational simulations were mainly games.

3.4 Counting Articles About *Simulation Methods* and Their *Area of Application* in HE

In Sects. 3.2 and 3.3, only some examples of articles from the literature on simulation in HE are presented due to the huge number of such articles, running between 4223 and 99,026 (based on line # 1 of Table 3.1). To get an idea about the frequency of publications on the various simulation methods and the areas of application, this section provides the relevant enumeration. Section 3.4.1 counts the number of articles on each simulation method in general versus their count in HE (higher education). Section 3.4.2 counts the number of articles on each application *area* in general versus their count in *HE*. Section 3.4.3 presents the number of articles on each simulation *method by area* of application as applied to HE. In all three tables of this section, the count of articles was performed in the Web of Science (WoS) assessed October 2020. In Table 3.1 and Table 3.3, column 1 counts

Table 3.3 Number of articles on *areas of applications* and *simulation* in general and in HE[a]

Areas of applications	Number of articles			Percentage	
	1. Area in topic	2. Area and HE in topic	3. Area and HE in title	Column 2 from 1	Column 3 from 1
1. Transportation	2,687,092	182,392	8431	6.788	0.314
2. Industry	1,535,172	172,676	6993	11.248	0.455
3. Knowledge transfer	224,253	34,688	3886	15.468	1.733
4. Marketing	7,730,644	767,185	43,741	9.924	0.566
5. Projection	274,406	13,867	351	5.053	0.128
6. Enrollment	697,521	353,146	81,184	50.629	11.639
7. Faculty	217,093	123,689	9714	56.975	4.475
8. Teaching	1,803,689	450,020	49,850	24.950	2.764
Total	15,169,870	2,097,663	204,150	13.828	1.346

[a]Assessed from the Web of Science on Oct. 2020. See Appendix 1, on synonyms for "HE" and "areas" of application

the number of articles with methods/area in their *topic*. Topic means that the search word (or one of its synonyms, see Appendix 1 for the synonyms for each search word) appears either in the *title*, abstract, or keywords of the article. Column 2 counts the number of articles with HE and method/area in their *topic*. Column 3 counts the number of articles with HE and method/area in their *title*. Obviously, for each method, column 2 articles are included in column 1 articles, and column 3 articles are included in column 2 articles. Thus, the count of column 2 is always less than the count in column 1, and the count of column 3 is less than the count of column 2.

3.4.1 Number of Articles on Simulation Methods

As shown in Table 3.1, the simulation methods were divided into two groups: *analytical simulations* methods listed in Sect. 3.2 and *educational simulation* methods listed in Sect. 3.3, used mainly for pedagogic purposes. *Educational simulations* articles out-number the *analytic simulation* articles, since the former are intended for a wider audience, i.e., those disciplines which do not require as much mathematical proficiency as disciplines where *analytic simulation* is used. Even the authors of educational simulations come from a variety of disciplines, such as health professions and education, in addition to the STEM disciplines.

Obviously, out of ten simulation methods listed in Table 3.1, the method with the highest number of articles in all three columns is the generic method *simulation*. Moreover, *simulation* appears more than all the other nine simulation methods combined. For example, in column 1 in general, there were 1,834,848 articles on *simulation* methods, versus a total of 381,769 for *analytic simulation* and 556,052 for *educational simulation*. Obviously, there are overlaps. For example, in some articles for method 4, *discrete-event*, the word *simulation* is often added, thus such article will be counted twice in the total of *analytic simulation*. Thus, in the last row of Table 3.1, the total count is given without the first row of method 1, *simulation*.

In column 2, where the search words *HE* and the specific simulation *method* appear in the *topic* of the articles, the total number of *analytic* articles is 20,245, while the number of *education* articles is 55,940. However, in column 3, where the search is for *titles* that contain the words *HE* and a specific *method*, the total number of *analytical simulation* articles is 575, while the number of *educational simulation* articles is 4590. This proves that *educational* simulations became very important during the last two decades. About 5% of the *analytical* simulation articles in WoS are in HE, where the search words are in the *topic* (percent of column 2 total from column 1), but 10% of the *educational* simulation articles in WoS are in HE. When the search words are only in the articles' *titles* (column 3 as a percentage of column 1) then the corresponding percent is 0.151% for *analytical* simulation and 0.825% for *educational* simulation.

Of the four *analytical* simulation methods in Table 3.1, *Monte Carlo* is the method with the largest number of articles in the first three columns (176 articles in column 3). There are overlaps between *Mote Carlo* and the other two stochastic *analytic* methods: *discrete-event simulation* and *agent-based simulation*. Nevertheless, each of these stochastic simulation methods alone has more articles than *system dynamics*. Note that the method with the smallest number of articles is *deterministic* in all three columns of Table 3.1.

From the five *educational* simulations, the *virtual* simulation method is leading with the maximal number of articles in the first three columns of Table 3.1—with 261,559 articles, of which 30,390 articles include *HE* in their *topic*, of which 2650 articles include *HE* and *virtual* method in their *title*. The method *game* has the second maximal number of articles in all three columns, and the method *simulator* is the third.

In summary, educational simulations have many more articles than analytical simulation methods. From educational simulations, the leading methods in terms of the number of articles in WoS are as follows in order of frequency: *virtual, game*, and *simulator*. The leading methods of *analytical* simulation are *Monte Carlo*, *discrete-event,* and *agent-based* simulation.

3.4.2 Number of Articles on Application Areas

Table 3.3 presents eight application areas where HE can be applied. The leading application areas, according to the number of articles in general (column 1), were *marketing*, *transportation,* and *teaching*. For *HE* and *area* of application in the *topic* of the articles (column 2), the order of leading application areas is *marketing*, *teaching*, and *enrollment*. For HE and area appearing in the title of the articles (column 3), the order of leading areas of applications is *enrollment, teaching*, and *marketing*. Note that Table 3.3 does not refer to simulation at all.

In summary, the leading application areas in HE are *enrollment, teaching*, and *marketing*. Overall, the number of articles in areas of applications as presented in Table 3.3, which come under the rubric of area in topic in column 1 (about 15 million articles), is much larger than the number of articles by methods in all three columns of Table 3.1 (1.8 million articles).

3.4.3 Number of Articles on Simulation Methods by Application Areas in Higher Education

Table 3.4 presents the number of articles with HE and *simulation method* in an article *title* by *area* of application in their *topic*. The assumption behind this is that most administrators and researchers in HE are likely to use HE and area of application in their title to attract a wider range of readers, and thus they tend to extend the method term to the keywords or abstract.

Table 3.4 Number of articles with HE[a] and area of application[b] by simulation method

	Area[b]:								
	1	2	3	4	5	6	7	8	
Methods	TRNS[b]	IND[b]	KT[b]	MKTG[b]	PROJ[b]	ENRL[b]	FAC[b]	TCH[b]	Total
1. Simulation	540	217	47	977	36	1900	96	1804	5617
2. System dynamic	13	19	6	50	10	15	6	21	140
3. Monte Carlo	19	46	1	83	5	14	13	10	191
4. Discrete- event	17	9	1	61	0	50	11	40	189
5. Agent- based	25	7	2	40	1	13	2	14	104
Sum of methods 2–5	74	81	10	234	16	92	32	85	624
6. Virtual	219	74	42	455	4	1036	66	1003	2899
7. Simulator	48	12	4	85	2	306	10	350	817
8. Game	59	60	32	216	3	770	29	390	1559
9. Box trainer	0	0	0	0	0	7	0	5	12
10. Manikin	0	1	0	4	0	86	2	71	164
Sum of methods 6–10	326	147	78	760	9	2205	107	1819	5451
Total	940	445	135	1971	61	4197	235	3708	11,692
Total w/o simulation	400	228	88	994	25	2297	139	1904	6075

[a]See synonyms used in Appendix 1. HE (higher education) and application area in article *title* and *method* in article *topic*

[b]Abbreviations of areas of applications are: TRNS —transportation, IND—industry KT—knowledge transfer, MKTG—marketing, PROJ—projection, ENRL—enrollment, FAC—faculty, TCH—teaching

The figures in Table 3.4 strengthen the results of Sects. 3.4.1 and 3.4.2 (as reflected in Tables 3.1 and 3.3), although the counting method changed. Again, the leading simulation methods, with the maximal number of articles, are the generic term *simulation,* and then come the three leading *educational* simulations: *virtual*, *game,* and *simulator* (last column of Table 3.4). Again, the leading application areas, in terms of number of articles, are *enrollment, teaching,* and *marketing* (last row of Table 3.4). Within each of the three leading methods: virtual, game, and simulator, the maximal number by area follow the same order holds as the total: enrollment teaching and marketing.

For example, focusing on the generic *simulation* method by application areas in HE (row 1 in Table 3.4), the use of *simulation* for *enrollment* has the maximal number of articles (1900 articles, in row 1 column 6). The area of application with the second largest number of articles by area is *simulation* for *teaching* (1804 articles, in row 1, column 8). The area of application with the third largest of articles is *simulation* for *marketing* (977 articles, in row 1 column 4), the same above order of applications areas (*enrollment, teaching*, and *marketing*) applies for the number of articles of each of the main three simulation methods: *virtual*, *game* and *simulator*—in lines 6, 8, 7, respectively.

Similarly, looking at the last column of Table 3.4 (total) the simulation methods with the maximal number of papers and their orders are *virtual*, *game,* and *simulator* (2899, 1559, and 817, respectively). The same order applied to the three leading application areas: *enrollment, teaching*, and *marketing* (rows 6, 8, 7, respectively).

In the following is a comparison between the *analytic simulation* methods and the *educational simulation* methods:

(a) ***Analytic simulation***—four methods: *Monte-Carlo, discrete-event simulation, system dynamics*, and *agent-based simulation,* with 191, 189, 140, 104 articles, respectively, and 624 articles in total compose only 10.27% of the articles.
(b) ***Educational simulations***—five methods: *virtual, games*, *simulator, manikin, and box trainer,* with 2899, 1559, 817, 164, 12 articles, respectively, and 5471 articles in total compose 89.73% of the articles (out of 6075).

Obviously, the *educational simulation* methods comprise most of the articles in Table 3.4, almost 90%, in the WoS during the period 2000–2020.

Moreover, each of these simulation methods: *virtual, game,* and *simulator*; their areas with the maximal number of articles are the same: *enrollment, teaching,* and *marketing* (as shown in Table 3.4, in the intersect of these three methods and three areas). These nine entries (of *virtual, game, and simulator* methods by *enrollment, teaching, and marketing* areas) compose 4611 (76%) of the articles in Table 3.4, not including the generic method *simulation*. Namely, 12.5% of the entries of Table 3.4 cover 76% of the articles—thus, the Preto rule basically holds true.

As shown in Appendix 1, *marketing* (MKTG) area of application includes the following synonyms: finance, financial, strategy, ..., policy models, ..., planning, budgeting, cost, costing, managerial, management, administration, and administrative. Section 3.2 shows that analytical simulations are used mainly in marketing areas, as listed here. Indeed, we see in Table 3.4 that for each of the four analytic simulation methods, including the sum of the *analytic simulation* methods (line of "Sum of methods 2–5" in Table 3.4), marketing has the highest number of articles, while the *educational simulation* methods achieve their maximum in enrollment and teaching, and marketing is in the third place.

In summary, as seen in Table 3.4, the *educational simulation* methods have by far more articles than *analytical simulation* methods. The educational simulation methods with the largest number of articles are *virtual, game*, and *simulator*. The areas of applications with the maximal number of articles are *enrollment*, *teaching*, and *marketing*. However, the *analytical simulation* methods have the maximal number of articles in the *marketing* area of application as expected, while *enrollment* and *teaching* areas of applications are in the second and third places.

3.5 Summary and Conclusions

Simulation is one of the leading methodology/tool in HE, besides its use in Industry, military, leisure, etc. The number of articles in WoS during the recent years on simulation, in general, is over 1.8 million articles; of which simulation in HE composes about 10%. This chapter provides an overview of simulation in HE: first by classifying the simulation methods in HE by type, second by pointing at areas of application where simulation is used in HE; third by verifying the most used simulation methods and their areas of application in HE. We suggest classifying the simulation methods in HE into two main types of simulation models: a. *analytical simulation* methods and b. educational simulation methods—each is divided into sub-methods.

In summary, we found that *educational simulations* have many more articles than *analytical simulations* (in WoS during 2000–2019). The leading simulation methods (in terms of number of articles) are (1) V*irtual* (2) *Game* and (3) *Simulator*—all three methods are from the *educational simulations* group.

The advantages of *educational* simulation are that they are characterized by safety (e.g., in medicine) and accessibility (virtual Lab); are more economic with respect to training, with less disruption of training than exists in real situations (health system simulations, or business game); have more flexibility in training under various conditions, and enable flexibility in training scheduling.

We consider here eight areas of application of simulation in HE: (1) *transportation* (2) *Industry* (3) *Knowledge transfer* (4) *Marketing* (5) *Projection* (6) *Enrollment* (7) *Faculty* (8) *Teaching* (see synonyms used for each area in Appendix 1). The leading areas of application in HE in terms of number of articles are *(1) enrollment, (2) teaching,* and *(3) Marketing*. Looking at the ten simulation methods by eight areas of application in HE (Table 3.4), the same three simulation methods (*virtual, game*, *and simulator*) are leading within each area of application and mostly in the same above three leading areas of applications (i.e., *enrollment, teaching,* and *marketing*). However, the *analytical simulation* has its maximal number of articles in *marketing*—*enrollment* and *teaching* are the next in the number of articles.

The advantages of analytic simulation are manifold. They do the following: improve the ability to choose from alternatives by easily testing various options, policies, and scenarios without disrupting the real system; diagnose problems in complex situations; accelerate real life processes in time via simulation runs, predicting future development and "what if" behavior of the system; and enable visualizing the system operation.

The main disadvantage of simulation methods, in general, is that simulation is an imitation of the real system. Other disadvantages include the need to train the users and teachers to use the specific simulation model with its technicalities, assumptions, options, applications, and interpretation of the results. Verification and validation of the simulation sometimes are neglected, and sometimes, effectiveness/cost value may be questionable.

This overview is useful for developers of HE simulations and for administrators at all levels of HE institutions, including heads of departments, deans, consultants, and councils for HE at the state level, so they can become aware of the growing use of simulations in HE and their potential use.

For future research, enlarging the synonyms and avoiding double counting will improve the accuracy of the articles' counting results. There is a lack of literature reviews on three of the *analytical simulation* methods: *discrete-event* simulation, *agent-based* simulation in HE, and *deterministic and other* simulations in HE. Finally, there is a need to review the economic viability of the various educational simulation tools (digital and virtual) for HE. The COVID-19 pandemic may increase the utilization of the various simulation tools. It would be interesting to study the change in the use of educational simulation, mainly online and web-based simulations, a year and more after the pandemic will be over. Moreover, it remains to be seen what forms of virtual classroom and the virtual university will evolve (see Almog & Almog, 2020).

Appendix 1: Synonyms for: (a) Higher Education (b) Simulation Method (c) Areas of Application

a. Higher Education:
Higher education: academic, college, university, tertiary education, medical education, nurse, nurses, nursing, pharmacy, undergraduate education, undergraduate, airway management education, medical, engineering, business education, internship, higher professional education
b. Simulation Methods:
1. Simulation: simulating, simulate, simulation-based
2. Industrial dynamic, industrial dynamics, system dynamic, system dynamics, system-dynamic, dynamic simulation
3. Monte Carlo

(continued)

4. Discrete-event: discrete-event, DES
5. Agent-based: agent-based, ABS, ABM
6. Simulator: simulators
7. Game: games
8. Box trainer: box training.
c. Areas of Applications:
1. Transportation: transshipment, assignment, project management, CPM, Gant, PERT, network, networks, location, scheduling, timetabling
2. Industry: logistics, maintenance, reliability, inventory
3. Knowledge transfer: knowledge management, management of knowledge, R&D research and development, patent, patents, industrial park, industrial parks, incubator, incubators, entrepreneurship, entrepreneurial
4. Marketing: finance, financial, strategy, strategic, balanced scorecard, BSC, efficiency, efficient, accounting, investment, revenue management, policy modeling, policy model, policy models, renovation, international, internationalization, planning, budgeting, cost, costing, managerial, management, administration, administrative
5. Projection: projecting, forecasting, forecast
6. Enrollment: student/students
7. Faculty: staff, manpower
8. Teaching: teach, practice, practicing, train, training, pedagogy, pedagogic, practitioner

Appendix 2: Taxonomy of Simulation Models Applied to Higher Education

Authors (year)	Type of simulation[a]	HE area	Levels HE hierarchy	Country of application
Weathersby (1967)	Regression	Costs of departments	University by department	USA, UC Berkeley
Baisuck and Wallace (1970)	DES	Enrollment projection	University and regional	USA
Hopkins (1971)	Deterministic. simulation	University planning	University	USA
Sinuany-Stern (1978)	Simulation and optimization	Budgeting and planning	Community college (CC)	USA (multi campus CC)
Kennedy (2008)	SD	Policy issues	All levels	Review 1975–2005
Schellekens et al. (2010)	DES	Program organization	University	The Netherlands
Kennedy (2011)	SD	Policy and pedagogy	All levels 40 articles	Review 1972–2008

(continued)

Authors (year)	Type of simulation[a]	HE area	Levels HE hierarchy	Country of application
Galbraith (2012)	SD	Various	Various	Methodology
Voyer et al. (2012)	SD	Performance	Business sch.	USA
Hussein and El-Nasr (2013)	SD and genetic algorithm	Budget allocation and quality	Institutional	Methodology NetLogo
Larson et al. (2014)	R0, reproduction number	Supply and demand of Eng. PhDs	National	USA
Brailsford and De Silva (2015)	SD	Supply and demand of dentists	National	Sri Lanka
Gu et al. (2015)	ABS/ABM	Academic activities and teaching	All HE levels 35 articles	Review during 1997–2013
Gu et al. (2015)	ABS prototype in NetLogo	Researchers publications strategy	University by department by researcher	Australia
Kara (2015)	Stochastic SD	Stud. Supply and demand and quality	National	Turkey
Fateh Rad et al. (2015)	SD	Strategic—industry relations	University Regional	Iran
Little (2015)	DES and ABS	Quality improve	University	General
Strauss and Borenstein (2015)	SD Undergrad. enrollment	Long run planning, strategy	National HE pub-lic/private sector	Brazil
Dandagi et al. (2016)	SD and Structural equations	Strategy Question-naire factor anal.	University	India
Oltean et al. (2017)	DES—facility planning	Building viability	Public university	Romania
Al Hallak et al. (2017)	SD—facility & faculty plan	Enrollment Mgmt.	Regional private sector	Syria
Faham et al. (2017)	SD	Strategy	University	Iran

(continued)

Authors (year)	Type of simulation[a]	HE area	Levels HE hierarchy	Country of application
Ghaffarzadegan et al. (2017)	SD—Student quantity vs. quality	Policy Edu. job mismatch	Regional	Methodology
Zaini et al. (2017)	SD	Strategy	University	USA
Kara (2018)	SD—Structural equation	Quality and productivity	University	Turkey
Tan et al. (2019)	Discrete-timed model, Parallel systems	Quality of Peer review process	International	China
Siniksaran and Satman (2020)	Simulation	Universities ranking	Universities	Review

[a]SD—System Dynamics, DES—Discrete-event Simulation, ABS—Agent-Based Simulation also ABM (Agent-Based Model). [b]indicating number of reviewed papers in a review paper

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Chapter 4
Managing Minds: The Challenges of Current Research Information Systems for Improving University Performance

Gad Yair

> *"Data and analytics help inform decision-making. Rendering decisions without accurate, robust, and topical data is the same as flying blind, relying on intuition, "gut feel," and unreproducible methods."*
>
> *(Peter Maglione, CEO, Academic Analytics)*

Abstract This chapter describes the failure of Current Research Information Systems (CRIS) to modernize routine managerial tasks involved in academic administration. It argues that most universities maintain traditional decision-making procedures in regards to hiring, promotions, preparation of annual reports, and submission of portfolios for accreditation and assessment. I argue that developers of CRIS programs failed to appreciate the tasks of academic management. At the same time, management teams seem reluctant to change traditional academic practices. I discuss reasons for this disconnect and suggest ways to close the gap so as to modernize academic decision-making in universities.

Keywords Current Research Information Systems (CRIS) · Higher education · Academic management

4.1 Introduction

Two decades into the twenty-first century, many universities still administer central academic procedures without accurate and robust research data. Top and middle-level administrators carry out organizational tasks like the hiring of new faculty, conducting promotion procedures, submitting annual reports, and to a lesser extent

G. Yair (✉)
Department of Sociology & Anthropology, The Hebrew University of Jerusalem, Jerusalem, Israel
e-mail: gad.yair@mail.huji.ac.il

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preparing for accreditation and assessment exercises through manual procedures. Rarely do they rely on new digital tools that appeared on the academic scene during the past decade. Indeed, Current Research Information Systems, or CRIS programs, had promised to solve those problems while modernizing the abovementioned tasks.

However, they have not. Both parties share the responsibility for failing to modernize academic management by implementing CRIS programs. The problem results from problematic marketing strategies by major companies; it also results from an origins story in library science. However, the disconnection also results from faculty resistance and from top administrations' misspecification of academic needs.[1] But as a result, resources are wasted, and academic units are left unaccountable.

The current chapter seeks to connect the two spheres by providing examples for possible specifications and their academic rationales. It urges university leaders to abandon current "medieval" practices by adopting digital tools. It calls on CRIS developers to better cater to the routine needs of academic management. With joint efforts, both sides can help universities to close the digital divide that separates many of them from modern organizational realities.

A caveat: This essay benefits from a decade-long experience as the person who developed CoolCite, one of the first CRIS programs on the market. I am also a science sociologist, with keen observations of Israeli science and Israeli academia (Yair, 2019a, 2019b). I gained comparative perspectives on the problems of integrating CRIS programs into academic decision-making processes through visits to American and European universities as well. Surprisingly or not, I found most universities share similar disjuncture between the medieval realities of their academic management and leading technological advances in the field of knowledge management. I hope my call below helps to close this gap.

4.2 Context: Accountability and Transparency of Research Outputs

As the global race for scientific innovation speeds up, administrators are challenged to provide stakeholders with data about research performance and impact. They face demands to lower costs while increasing productivity and impact. Multiple stakeholders pressure universities to modernize while becoming accountable and transparent. Government allocations for research require more precise data about productivity ever. Private donors pend endowments on data concerning academic excellence. Corporations hinge resources for research by demanding transparent

[1] As a developer of a CRIS program I had the opportunity to follow Israeli University presidents and rectors drag the process for more than a decade. First attempts for national implementation took place in 2008. Only in 2017 has PURE by Elsevier won a bid. We are at the verge of 2020—and we are yet to see implementation (checked with the bidding agency, Machba, November 2019).

data about scientific outputs. As a result, boards of governors entrust university leaders with responsibility for maximizing scientific innovation within growing budgetary constraints. To answer those diverse stakeholders, administrators need robust evidence about inputs (e.g., funding, positions, FTEs) and outputs (e.g., students, patents, publications, prizes, citations). They need information about successful units as well as about bottlenecks and areas of malfunction.

With growing public pressures for accountability and transparency, top university administrators are therefore responsible for two interrelated tasks: (A) Improving the conditions that allow scientists to maximize their research potential; (B) Employing Current Research Information Systems (CRIS) for responsible and transparent decision-making procedures at different levels under their jurisdiction. They are assisted in attaining the first task by abundant research concerning management practices. Indeed, decision-makers have a knowledge-base from which to extract organizational strategies for increasing scientific productivity and impact. For example, studies have pointed to organizational levers like funding sources, monitoring practices, or performance-based incentive programs. However, leading university administrators still regard the second area as *terra incognita*. Up until recently, indeed, they had little data for supporting evidence-based managerial practices or the digital tools to support routine, labor-intensive administrative procedures. Furthermore, they often lack familiarity with new technologies for academic management or the skills to use them. As a result, some university leaders still oversee their universities while relying on outdated, oftentimes arbitrary, and possibly biased procedures for decision-making. Some just keep using the practices that Peter Maglione criticized, namely "flying blind, relying on intuition, "gut feel," and unreproducible methods."

In response to those growing needs, entrepreneurs have developed tools for the management of academic information that supposedly serves university administrations. Giants like Thomson Reuters, Elsevier, Clarivate Analytics, and ProQuest envisioned offering administrators with digital tools for research management. Smaller innovative companies introduced alternative metrics for assessing individual or unit productivity and impact (Altmetrics). Indeed, CRIS programs like Esploro, Scival, Pure, and Vivo promised to bring universities up to speed into the digital revolution.[2] However, they missed central clients in University administration, since developers provided librarians, rather than administrators, with data and analytics for assessing science. True, some programs provide aggregated data arranged in multiple organizational levels; some standardized supply metrics for assessing journals and publications; and several enrich views on data by adding "alternative metrics" that broaden the scope of scientific assessments. However, most CRIS programs have remained detached from routine academic realities.

[2]These are but prominent examples. The field contains many other platforms. Readers are advised to see a taxonomy of those programs and their features here (extracted December 21, 2019): https://en.wikipedia.org/wiki/Comparison_of_research_networking_tools_and_research_profiling_systems.

Developers have offered sophisticated tools with horns and whistles, but they have mostly answered for needs of librarians and research managers. They thus failed serving universities in the main tasks that they conduct on an annual basis.

The current mismatch between advanced digital tools and routine university practices results from the fact that most companies in the field arrived from scientific publishing and library management. As a result, they designed CRIS programs with the intent to satisfy the needs of university librarians, not administrators in the front where science is managed. One often observes this biased orientation in marketing efforts: CRIS programs mainly target libraries and librarians. In some cases, they also target research administrators. Consequently, those advanced digital products have largely remained unused during central, labor-intensive academic procedures that task university administrations on an annual basis. Indeed, scrutiny of main academic procedures suggests that department chairs, deans, provosts, rectors, and university presidents have remained aside from the digital revolution. Those are truly smart people; their technologies, however, are a bit more advanced than pencil and paper.[3]

The present chapter seeks to mend the disconnection between current research information systems and routine academic operations in universities. It first reviews the development of the burgeoning field of current research information systems and explains why their publishing and library orientations contributed to the disconnection. Second, the chapter shows where CRIS developers and administrators need to meet to finally connect the digital revolution to traditional, almost medieval administrative practices. To do so, it focuses on major annual, labor-intensive organizational procedures. It demonstrates how administrators would benefit from appropriately specified CRIS programs that would target routine organizational needs. Specifically, it dwells on hiring practices, promotion procedures, preparation of annual reports, and the submission of assessment and accreditation portfolios. Most universities currently carry those routine organizational practices through the same procedures that they used three decades ago, when Bill Gates described the digital revolution and the paperless office (B. Gates, 1995). It is time for department chairs, deans, rectors, and universities to jump on the digital bandwagon. With adapted CRIS programs, they would be in a better position to support scientific innovation, productivity, and excellence. Furthermore, by redesigning current research information systems, developers can boost their integration with the digital campus, advancing beyond purveyors of research information systems. Their products do have the potential to animate and modernize the university of the twenty-first century.[4] But they need to better address administrative needs.

[3]Some administrators boast that they moved to Dropbox sharing CV documents rather than using printed papers. This is hardly a technological advance.

[4]The organizational challenges I describe and my suggestion for software development are set from a bird's eye. Each should be carefully studied with possible adaptations to local institutional variations.

4.3 Libraries Are Not Universities: The Problematic Evolution of CRIS Programs

CRIS programs are the applied side of the field nowadays called "The Science of Science" (Fortunato et al., 2018; Eugene Garfield, 2009; Price, 1963). This century-long research tradition was inaugurated by Alfred Lotka, who was the first to model the rarity of scientific excellence (Lotka, 1929; Yair et al., 2017). The revolution in this field—and its commercialization—gained pace with the studies of Eugene Garfield, who founded the area of bibliometrics.[5] Garfield's studies expanded the understanding that distributions of publication productivity, paper citation counts, and journal impact factors[6] follow power-law or log-normal patterns (Eugene Garfield, 2009; Eugene Garfield, 2006; Eugene Garfield, 1970; E Garfield, 1972). His leadership gained followers in library science and library management. However, since his development efforts targeted librarians, he inadvertently created a limited trajectory for later technological developments in academic management.

The field of information science and scientometrics made tremendous technical advances with growing data availability (e.g., Web of Science, Google Scholar).[7] It was further buttressed by the incorporation of simple metrics for assessments of productivity and impact, exemplified by the H-Index[8] and its many adaptations and revisions (Hirsch, 2005; Mistele et al., 2019; Praus, 2019). In the last two decades, scholars have also introduced sophisticated research methods, coupled with network models and big data, for evaluating and assessing careers, programs, universities, and entire fields of knowledge (Sinatra et al., 2016; A. J. Gates et al., 2019). Social network platforms like Facebook and Twitter expanded available information about the impact and reach of research. They allowed innovators to come up with new tools for harvesting that information for assessing impact (e.g., PlumX).[9]

Those technical innovations led in some cases to multi-billion businesses. Small enterprising individuals who came up with ideas for extracting information and rearranging it for decision-making ended up being integrated into huge publishing

[5]Bibliometrics and scientometrics are fields of study that focus on scientific productivity and impact—which constitute the two main measures for ranking individuals, journals, and institutions in terms of success and prestige.

[6]Measures of impact factor (IF) denote the number of expected citations for publications in Journal X in the following year or two. The higher the IF, the more citations garnered by papers. This measure serves as a proxy for journal quality and its prestige. It is also a proxy for the centrality of journals in research fields.

[7]Some administrators use Publish or Perish, a software that collects publication data from Google Scholar. Many fail to appreciate problems in Google Scholar. See the rich website of P&P developer, Anne-Wil Harzing in: https://harzing.com/resources/publish-or-perish (extracted December 21, 2019).

[8]The H-Index measures productivity (number of publications) and impact (number of citations) with a single number that makes it highly popular and effective.

[9]PlumX measures number of mentions in social network platforms like Facebook, Twitter and Mendeley. See: https://plumanalytics.com/learn/about-metrics/ (extracted December 21, 2019).

or library outlets. For example, Eugene Garfield created Current Contents, the Science Citation Index (SCI), and the Journal Citation Reports, a family of tools that were gradually incorporated into Thomson Reuter's products. Those tools were later bought by Clarivate Analytics, nowadays offering a large suite of solutions to researchers and institutes (e.g., Endnote, Publons, InCite).[10] The library of Cornell University developed VIVO for integrating internal information.[11] This local CRIS system now serves 140 institutes across more than 25 countries. Similarly, Aleph, originally developed at The Hebrew University of Jerusalem to improve its library collection, morphed into Ex-Libris, which was later bought by ProQuest—now offering its own CRIS program named Esploro.[12] Similarly, a small Danish company named Atira A/S developed Pure, one of the first full-fledged CRIS programs—only to be bought by Elsevier, another giant of scientific publishing.[13] ORCID, another digital platform, created a single ID code for each scholar, thereby more accurately archiving scholars' publications.[14] However, as most other CRIS programs—this important innovation suffers from the underidentification of publications, mainly in the humanities and the social sciences. Such successful innovative platforms—and the fact that many companies compete for hegemony in this market—suggest that information about scientific performance has become an important asset in the competition for scientific excellence. However, most of those tools have remained on the limited track of library science. It is time to acknowledge, then: the administration of academic activities requires a very different outlook on the information. It, therefore, requires expanding the capacities of current research information systems.

In what follows, I show how developers need to think of those capacities so as to help department chairs, deans, rectors, and presidents perform their routine, data-rich academic tasks.[15] By developing additional technical solutions for those needs, CRIS programs promise to lower operational costs and workload while improving transparency and efficiency. Their revised capacities promise that researchers and universities would be able to make better use of time and resources for the main task they are entrusted with: Advancing science for health, knowledge, and the improvement of the human condition.

Both sides need to adapt to current practices. CRIS developers need to ask themselves the following questions: Why have we failed to enter into routine academic practices of university administration? What do we currently lack in

[10] https://clarivate.com/webofsciencegroup/ (extracted December 21, 2019).

[11] https://duraspace.org/vivo/ (extracted December 21, 2019).

[12] (extracted December 21, 2019).

[13] https://www.elsevier.com/solutions/pure (extracted December 21, 2019).

[14] https://orcid.org/ (extracted December 21, 2019).

[15] Marketization of CRIS program faces another organizational problem. Universities provide units—departments, research centers, faculty units—with autonomy. Those units create their own websites. They are at times responsible for integrating digital platforms through their own discretion and with their internal budgets. Market strategies should allow flexible specifications of service.

functionality? What revisions do we need to make? On their part, university administrators need to ask the parallel question—which CRIS programs best answer for our mainstream academic needs? How can we make sure that we run our university with the tools that would boost our performance and ranking in the global race for scientific excellence?[16]

4.4 Academic Managerial Routines in Need of Reform

In the following four sections, I review major institutional operational requirements. Those operations demand immense organizational efforts and coordination. However, to date, most universities keep handling those routine tasks through manual procedures. I focus on what I deem to be major areas of intervention for CRIS programs: Hiring procedures, promotion procedures, preparation of annual reports, and the submission of accreditation and assessment portfolios.

4.4.1 Recruitment of New Faculty

Hiring of new faculty stands at the heart of university decision-making. It involves in this complex but routine operation selection committees, department chairs, and deans. Furthermore, in many universities, new nominations require the approval of rectors and presidents. In some countries, they also necessitate state approval. During this tedious and tasking annual process, hundreds of applicants flood universities with CVs, research statements, and recommendation letters. Facing this avalanche of papers and PDFs, faculty have to select the best candidate out of the pool. They mostly do so through a burdensome manual process, mostly non-transparent and at times with little accountability regarding standards of evaluation. Either way, by the end of that annual process, universities replace between 3% to 5% of their faculty (as similar numbers of faculty members retire). Evidently, systematic miscarriage of hiring responsibilities means that over the long haul, the university and departments may lose budgets and esteem and deteriorate in institutional rankings. Therefore, department chairs and deans need to make sure that their hiring procedures are optimal. Rectors and presidents need to be accountable for making sure that their university hires the best candidates.

In facing this challenging annual task, decision-makers often grapple with important questions. How good were we in selecting candidates? How accurate were

[16]In appraising "who needs to change," CRIS developers need to appreciate that universities are heavily regulated by ordinances and collective agreements. Academic decision-making procedures are resistant. It is therefore the task of information giants to adapt their products to the realities and regulations of academic life.

our nominations across years? Are there units that keep electing candidates of lesser quality? Were our rival departments or institutes able to recruit faculty with better long-term performance? Those are important questions. However, current organizational practices—often paper-based—do not allow university governing boards to oversee hiring practices truly. Furthermore, with hundreds of applicants across years, departments in competitive markets currently lack systematic information about their capacity to attract and maintain the best talent. They may have anecdotal stories, but they are basically clueless.

In answering this challenge, CRIS programs should play critical roles in the management and assessment of hiring procedures. This is especially true in areas like physics and the life sciences, where the training of young scientists continues for five or more years of post-doc. In such fields, candidates have already published papers and accumulated performance data that allows making decisions on proximate evidence. In fields that attract candidates immediately after graduate school (e.g., economics), it is post hoc comparisons that become critical.

Advanced CRIS programs should help departments assess candidates during the hiring process. They should also help deans and provosts by providing answers for post hoc assessments. Indeed, with appropriate data models, CRIS programs should allow departments to create annual groups of candidates for managing the selection process. They should help search committees in weighing their candidates by using objective and transparent evidence. For example, they should support faculty assessments of candidates by allowing them to quantify recommendation letters. They should also allow faculty to score assessments of applicants' academic merit (by evaluating contributions in papers and job talks). CRIS programs should provide transparent weighted scores that rationalize the process of hiring. They should thus guarantee rectors and presidents that lower-level decisions are backed by evidence. Furthermore, to allow post hoc evaluations, CRIS programs should continually harvest applicants' publication productivity and their impact. This would allow departments and higher level administrators to assess hiring accuracy.

4.4.2 Promotion Procedures

Academic career ladders motivate faculty to maintain productivity across the years. They celebrate excellence and reward effort and impact. To maximize the human potential of their faculty, some universities created four career stages, others three. Large universities handle hundreds of promotions per year; deans often oversee dozens. Either way, each promotion creates abundant workload and data. Each requires a committee, up to seven recommendation letters, coupled with summation reports by the committee and department chairs. Each promotion also requires approval by higher level committees. Such procedures often last a year to conclude, sometimes longer, oftentimes due to bottlenecks, workload, and forgetfulness. Since procedures are secretive and often employ opaque standards, many people mistrust the system of promotions. Lack of clear criteria often means that non-academic justifications may contaminate the process and taint career ladders' meritocratic rationale. Indeed, political and social biases at times position underachieving faculty in higher professorial positions than more prolific professors, raising public concerns over transparency and fairness regarding university promotions.[17]

Those problems are exacerbated by highly diverse disciplinary cultures (Becher & Trowler, 2001). Decision-makers often grapple with comparisons between physicists—who publish in large groups and with immense publication counts—and humanists, who mostly opt to publish books as single authors (Elisabeth S. Clemens et al., 1995). The problem of disciplinary differences at times appears even within faculty units. Anthropology, for example, opts for publication standards along the tradition of the humanities, whereas psychologists take to the norms of the life sciences. But even within psychology—committees are challenged in comparing neuroscientists with social psychologists. Alas, those disciplinary differences allow faculty to make ad-hoc arbitrary decisions about promotions. Department chairs often inflate promotion files with the rhetoric of excellence with little supporting evidence. Higher level committees rarely consult historical data, even in aggregated forms—thereby increasing doubts about the fairness and equal conditions. Alas, few universities manage those burdensome procedures with robust evidence about the timeliness, fairness, and meritocracy of promotions.

CRIS programs can play a significant role in correcting for those persistent organizational challenges. Essentially, promotion files can be likened to submitted papers for journals. For example, systems like Editorial Manager by Aries manage the entire workflow from the submission of papers up to publication. It accepts submitted manuscripts, helps editors elect reviewers, and collects revision decisions with follow-up procedures until a final decision—all in one digital environment. CRIS programs should adopt similar features for the handling of promotion procedures. They should allow candidates for promotion to upload their CV, academic statement, and sample papers. The program would help committee or department chairs in selecting appropriate recommenders while verifying that they are independent and in a good position to provide references. Similar to other document tracking systems, it should deliver all files, manage reminders, and provide analytics about the timing of all elements during the procedure (e.g., time from initiation to end, reviewers' timeliness, and committee deliberation efficiency).

Furthermore, CRIS programs like VIVO or PURE should use their strengths in providing promotion committees with automatic yet quantitative assessment of CVs—e.g., number of publications, citations, H-Index, journal impact factor figures, with all metrics standardized for the field. They should present collaboration networks and information about grants awarded. They should integrate information about teaching and student evaluations—thereby providing a rounded, multiple assessments of excellence (Boyer, 1990). They should also provide clear evidence

[17] In 2012 I conducted an Israeli faculty survey with more than 1400 academics replying. 47% said the promotion criteria are opaque; 33% stated that promotion criteria are not applied equally; 34% replied that promotion procedures are unfair. These are troubling statistics.

about the evolution of the career from prior promotion stages (delta figures). Universities should be able to upload historical files to help committees contextualize their decisions. With appropriate data design, those upended CRIS programs would, in time, create comparative benchmarks and allow all concerned to have a more efficient and trustable process of maintaining faculty motivation.

4.4.3 Preparing Annual Reports

Universities are often required to provide annual performance reports. Governing boards, state comptrollers, funding agencies, and other overseeing agencies request universities to provide detailed information about teaching, research, and public service. In some universities, academic units are also expected to supply annual reports about their performance to the provost. And some states require individual faculty members to submit their own annual reports. In facing those requirements, universities often engage in labor-intensive efforts of data collection and editing of information. Deans and department chairs spend administrative hours on reformatting reports arriving from different sources. Similarly, individual faculty members spend dear time in organizing their CV, writing their annual report while specifying objectives for the following year. It is clear that those activities derail universities and faculty from their main tasks, namely engaging in research and teaching.

CRIS programs should make most of this organizational hassle go away. By integrating different institutional databases (e.g., teaching assignments, grants, research outputs), they should provide automatic reports across various areas of faculty research, teaching, and service. They should supply universities with templates for reports starting from the individual faculty level, through departmental reports, up to aggregated reports at the university level. Indeed, comprehensive CRIS programs would eventually digitize the entire campus, allowing administrators to produce quick and updated reports with little human intervention. Furthermore, current technologies allow creating PowerPoint presentations and Word or PDF documents with pre-populated elements that simply update with new data. Such elements include text that describes changes across time. For example, using ever-updating data, such automatic reports can describe improvement, stability, or point to mounting challenges. Such report templates should allow administrators to enter free text for further explanation. But rather than having administrative and professional employees toiling over long and repetitive annual reports, the entire process should be computerized. Click and submit.

This is a good example of where CRIS developers need to move out of their comfort zone in library databases. The challenge they face is integrating campus life across different systems. As much as that may be challenging, campus life in most universities is already in digital format—but scattered. Courses are computerized. Faculty members are assigned to specific courses, with data about course type and level (e.g., undergraduate), number of students, possibly with course grades and grade distribution. Similarly, universities maintain information about research grants in digital format. They record which faculty members hold grants, the sum of grants, the source, the length of time, etc. CRIS programs are but steps away from integrating those currently operating databases. There are protocols for data transfer; there are local computer administrators that can share responsibility for making data availability.

Having such integrated capacities would critically ease the production of annual reports. However, they are also likely to generate new capacities for academic management. Advanced integrative CRIS programs would actually allow university administrators to ask new questions while creating new targets for improvement. For example, integration between grant and publication databases (as Academic Analytics partly enjoys today) would allow universities to ask new questions and create new efforts at reform. Here are some examples from the economics of science (Diamond, 1996; Sent, 1999; Stephan, 2012): "How many papers do we publish per $100k?" "Are there disciplinary differences in such efficiency quotients?" "Can we set benchmarks for improving the economic efficiency of our university?" Similarly, integration between library databases (e.g., ProQuest databases) with teaching databases would possibly transform discussions about the scholarship of teaching (Shulman, 2004). For example, administrators would be able to ask: "How updated are our syllabi?" "Which new items can substitute outdated ones?" "How many item overlaps do students encounter across our program?" Such questions truly get to the essence of university life, possibly reinvigorating current academic discussions about research and teaching. They would encourage faculty members to stay at the front of their discipline; they would thus guarantee that students are led towards those frontiers too.

4.4.4 Preparing Accreditation and Assessment Portfolios

Some disciplines require schools or departments to undergo external accreditation procedures (e.g., business administration). Some governments require universities or specific departments to engage in occasional internal or external assessments. Those requirements are costly and time-consuming. They necessitate department chairs to collect data from various sources. They require communication across administrative units and coordination with external regulations. If there is one task that administrators truly wish to be simplified, this is it. I know because I served as a chair when my department underwent national assessment; I know because I later assisted five more departments in other disciplines to submit their reports; I also know because I served in accreditation committees for the past two decades.

Familiarity with academic management platforms assures me that CRIS programs have a lot to offer on that front. They have faculty-level information on publications, citations, and the h-index. They probably hold information about the educational background of department members, possibly with the global rankings of graduating institutes and the majors or disciplines faculty members heralded from. They supply information about collaboration networks and about the internationalization of those networks. Some also provide Altmetrics in the form of shares across multiple academic and social networking platforms. Some tools integrate funding data with productivity and impact measures, allowing to present assessors with the smart evaluation of performance. In places where department chairs already enjoy such comprehensive systems, the complex and tedious tasks involved in the preparation of comprehensive and smart reports for accreditation and assessment committees are significantly eased.

As suggested in the previous section, the integration of CRIS systems with other campus databases would immensely improve available specifications while saving departments and universities significant resources. With improved specifications, the preparation of reports would require much less time. Data integration across campus would also minimize cross-unit bottlenecks in the coordination and transfer of required documents. Obviously, integrative CRIS programs would save costs. More crucially, however, they would help to generate new insights about institutional strengths and challenges.

For example, accreditation agencies often require a clear description of programs of study. How many professors are involved in teaching? How many are full-time faculty members, how many are employed as adjuncts? What are their academic degrees? How equal are teaching assignments across the program? What is the distribution of students' grades? Are there significant trends across the past five years in those indicators? With smart reporting capacities, answers to those questions should be easy. Similarly, integration with employment data would allow department chairs to provide evidence concerning faculty turnaround while specifying clear horizons concerning future retirements and the hiring of young or senior scholars. As stated above, most of those reporting tasks can be automated. CRIS programs should be able to generate graphs, spreadsheets, and PowerPoint presentations with a click of a button; they should also allow institutes to specify and generate their own reports without reliance on re-programming by external developers.

If CRIS programs do not provide those features yet—they should. If developers have not yet dwelled on cross-campus integration—they should. And if universities have not put forth such requirements—well, they obviously should.

4.5 Conclusions

Thirty years ago, I served as a research director in one of the units at the Municipality of Jerusalem. At the time, the administration adopted a new telephony system—one that could dial back, memorize numbers, and forward calls to other employees. During the demonstration, the general director of the municipality declared that "The problem is that the phones are now smarter than the employees." My observations of assimilation and implementation of CRIS programs in universities at times merit similar conclusions. During the past decade, I observed strong rejections of CRIS programs by universities—largely because they deliver on the promise of accountability and transparency. In many universities, faculty and leadership join hands in objecting to those programs, fearing that transparency would eventuate in greater public pressures. Furthermore, the targeting of marketing efforts towards librarians and research directors—rather than to presidents, provosts, rectors, deans, and department chairs—meant that the latter were able to maintain institutional inertia. One should reckon, though, that librarians have a minor role in institutional decision-making. Similarly, research directors are mostly occupied with questions of funding and grant management. Though those two offices are crucial and merit attention, they are not positioned at the central "command line" of most university organizations. As a result of this misalignment, most decision-making processes in higher education today have remained unaffected by innovative and integrative CRIS programs. In many cases, implementation is localized—being integrated into one or few units, allowing inertia to continue. As Peter Maglione was quoted above, the result is that in many universities and research centers, decision-making is still undertaken by "flying blind, relying on intuition, "gut feel," and unreproducible methods."

This, I surmise, is the main challenge for both sides. Administrators are responsible for changing institutional practices so as to base their decision-making on valid, reliable, transparent, and updated data. Developers of CRIS programs should better align their marketing and technical specifications with concrete routine institutional operations. Adopting technological innovations is important beyond market signaling; they should be followed by consulting universities on how to renovate their organizational decision-making routines. One needs to better care for the connection between administration and technology. It is, indeed, a challenge that the public demands university leaders to rise to.

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Chapter 5
Forecasting Methods in Higher Education: An Overview

Zilla Sinuany-Stern

Abstract Forecasting is the first, crucial stage of planning in any organization, and in higher education (HE) in particular. Student enrollment projections are particularly important, since they affect institutions' income, the number of faculty needed, facility requirements, budgets, etc. There are overviews of forecasting and classifications in general and for particular methods and applications. However, to the best of our knowledge, the last overview of forecasting in HE was published in 1997. Since then, two major approaches sipped from business to HE and became dominant in HE forecasting: data mining and questionnaires for marketing. The purpose of this chapter is to provide an updated overview of forecasting methods used in HE and their main areas of application. We cover a large array of forecasting methods and areas of HE application, we classify them, and point at examples from the literature, rather than providing an exhaustive annotated review, since there are too many publications in the literature on forecasting in HE. Counting the number of articles published in the Web of Science during the last 20 years, we find that, out of six main forecasting *methods* identified and classified, four methods are used most often in HE: regression, simulation, data mining (including its sub-methods), and questionnaires. Furthermore, four *areas* of application for forecasting are used most often in HE: enrollment, marketing, teaching, and performance. The two relatively new forecasting methods used in HE, during the last 20 years, are data mining and questionnaires. These two, relatively new forecasting methods, educational data mining and questionnaires (for marketing), are classified in this chapter as *active* forecasting methods in HE, as they provide the administrator with control over the forecast by pointing (directly or indirectly) at actions which can achieve a better-targeted forecast. While the old methods, time series, and ratio methods, are classified as *passive* methods with no control. Though regression and simulation forecasting methods are often *active*, they can sometimes be *passive*.

Z. Sinuany-Stern (✉)
Department of Industrial Engineering and Management, Ben Gurion University of the Negev, Beer Sheva, Israel
e-mail: zilla@bgu.ac.il

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5.1 Introduction

In general, forecasting activity levels is the first stage of planning in any organization or business. In higher education (HE) in particular, many activities are determined by student enrollments at various levels (e.g., department, university, state, and international) and in various categories (e.g., by year of study, state and out-of-state students, and by gender). Enrollment influences planning and budgeting, and more specifically income from tuition and from the state, amounts of various types of manpower needed, space needs, various costs, etc. Each of these parameters needs to be forecasted too, based on the enrollment projections.

In the general literature on forecasting Makridakis et al. (1983, 1998), in their classic book on forecasting methods and applications, provided rigorous mathematical formulations of many forecasting methods. They classified forecasting methods into four main categories: smoothing and decomposition, regression and econometrics, Box-Jenkins (ARIMA), and qualitative methods (similarly also Hyndman and Athanasopoulos, 2018). Armstrong and Green (2018) classified forecasting methods simply into two main groups: judgmental methods and quantitative methods (detailed classification in Sect. 5.3.2).

In the context of HE, Schmid and Shanley (1952) wrote about techniques for forecasting university enrollment in 1952, mentioning only two methods—ratio and cohort-survival—which were tested empirically on the University of Washington. They concluded that the ratio method is simpler but is not as accurate as of the cohort-survival method.

Brinkman and McIntyre (1997), in their comprehensive review on forecasting in HE, listed forecasting methods used for predicting enrollment and revenues in HE. They considered a wider range of forecasting methods than Schmid and Shanley (1952), but not as wide as Makridakis et al. (1983), dividing them into three main categories: quantitative methods, qualitative methods, and combined approaches. Their literature review was based on applications of the forecasting methods above in HE, covering articles during 1980–1995 (ibid.). Almost all the above-listed methods were taken from Makridakis et al. (1983) except ratio and cohort-survival which are specific to HE.

The purpose of this chapter is to provide an overview of the main forecasting methods in HE and the main areas of application. Examples are given, rather than an exhaustive annotated review, since the literature on forecasting in HE is very large, with thousands of articles over the last 20 years alone.

The contribution of this chapter lies first in two relatively new forecasting approaches, which became leading in forecasting in HE, not covered by Brinkman and McIntyre (1997): *data mining* for retention of students (as reviewed by Romero & Ventura, 2020) and *questionnaires mainly for marketing (*Oplatka & Hemsley-

Brown, 2021*)*. Secondly, we suggest a new approach where the various forecasting methods are classified into two main groups: *active* forecasting methods versus *passive* forecasting methods. Thirdly, by counting the number of articles according to forecasting method and areas of application in HE, along with examples from the literature, we get an overview of the applicability of various forecasting methods for HE planning and control.

The paper is organized as follows. Section 5.2 presents the forecasting methods, with examples showing their areas of application in HE, as summarized by Appendix 1. Section 5.3 presents types of classifications for forecasting methods in HE and various issues in HE forecasting. Section 5.4 provides a count of the number of papers published on each forecasting method in HE, from the total number of forecasting papers in general for each method, and for each area of application. Section 5.5 concludes the chapter.

5.2 Review of Forecasting Methods: Passive Versus Active Forecasting

In presenting the main forecasting methods, we divide them into six main groups, considering old methods (Brinkman & McIntyre, 1997; Makridakis et al., 1998) and newer methods of data mining (Romero & Ventura, 2007, 2020) and questionnaires for marketing (Oplatka & Hemsley-Brown, 2021); which were used more and more, during the last two decades, for forecasting in HE, as follows:

1. **Time Series**, including moving averages, exponential smoothing, fuzzy time series, and autoregressive methods (ARIMA).
2. **Ratio forecasting methods**, including the cohort-survival method and Markov analysis.
3. **Regression analysis**, which is very popular in forecasting, and is also included in data mining as a subsystem.
4. **Simulation**, including system dynamics and other simulation approaches, which are popular in forecasting and planning in HE and other fields.
5. **Data Mining (DM)**, which is often used for predicting student retention, even for individual students. Some DM subsystems, in addition to regression, are decision trees, random forests, neural networks, genetic programming, and grey models.
6. **Questionnaires** and surveys are often used for marketing.

The first two methods can be classified as *passive forecasting methods*, while the last four methods can be classified as *active forecasting methods* (see more explanation in Sect. 5.3).

The following is an explanation of each of the six forecasting methods above, with their sub-methods. For each of the forecasting methods listed, some examples are given from the literature in the next subsection. Detailed mathematical formulation is avoided to appeal to a wider audience of HE administrators.

5.2.1 Time Series

In time series, the forecast, F_{t+1}, of X_{t+1}, is a function of time series past values, $X_1, \ldots, X_t$. There are many time series methods; the three main methods are discussed here (see Chen et al., 2019). Here are the four main sub-methods of time series:

(a) **Moving average techniques** of order N: the forecast is calculated as an average of the actual observations over N prior periods $F_{t+1} = \sum_{j=t-N+1}^{t} X_t/\mathrm{N}$. As time progresses, each new forecast drops the observation from the oldest period and replaces it with the actual observation in the most recent period. For example, a moving average of order 10 considers the average of the last 10 periods. Pamungkas and Rofiqoh (2015) used a moving average of order 3 to forecast the number of students in a university (Batam University in Indonesia) during 2016–2020. As shown in Appendix 1, Lavilles and Arcilla (2012) also used a moving average.

(b) **Exponential smoothing** forecast F_{t+1} is a combination of the last forecast, F_t, and the last observation, X_t, so that $F_{t+1} = aX_t + (1 - a)F_t$, where $0 < a < 1$ is the weight given to the last observation. For example, Anggrainingsih et al. (2015) used exponential smoothing to predict the number of website visitors for a university in Indonesia. As shown in Appendix 1, others have also used exponential smoothing in HE, for example, Ge et al. (2013), Lavilles and Arcilla (2012), and Tang and Yin (2012).

(c) **Fuzzy time series** is an interval prediction for time series rather than a point. For example, Aladag et al. (2010) used a high-order fuzzy time series method in which fuzzy relationships are defined by feed-forward neural networks, and an adaptive expectation model is used for adjusting the forecasted values. The method is applied to enrollments at the University of Alabama. Ge et al. (2013) suggested integrating fuzzy time series with exponential smoothing. They also applied their method on enrollment data from the University of Alabama and showed that the method has a better performance compared to the other five forecasting methods, based on the mean-squared error. As shown in Appendix 1, Hwang et al. (1998) also used fuzzy time series for HE.

(d) **ARIMA—Auto Regressive Integrated Moving Average** methods are based on regression of the forecasted observation with its past observations (auto regression) $F_{t+1} = F(X_1, \ldots, X_t, E_1, \ldots, E_t)$,where E_t is the error of forecast F_t. For example, Chen (2008) used ARIMA to forecast student enrollment in Oklahoma State University. Enrollment data was given by term (spring and fall) and by type of student entering (freshman, transfer, readmission, and continuer). Sometimes, the set of first-order differences is used to obtain a linear functional relationship (when there is nonlinear behavior of the data).

5.2.2 Ratio Methods

Ratio methods use to be the main methods for enrollment projection, due to its simplicity and intuitive meaning. For example, historical data are used to calculate a time series of ratios between the total population of some relevant age group and the number of students in that age group (Sinuany-Stern, 1980). Another example is from Agboola and Adeyemi (2013), who projected university enrollment in Nigerian universities assuming 3.5% annual growth and projected the need for academic staff based on past faculty/student ratios by discipline. As shown in Appendix 1, others have used ratio models: Schmid and Shanley (1952), Sinuany-Stern (1984), and Allen (2013). Here are the two main additional sub-methods of the ratio method:

(a) **Cohort-survival method** is another widely used enrollment projection methodology, also referred to as the "grade progression ratio method." The approach develops retention ratios, which are associated with successive levels of academic attainment (grades). Given the total enrollment at the lowest grade for each of several years, cohort of students in the lowest grade is "aged" through the subsequent grades; the result being, in the simplest case, the distribution of enrollment by grade for any future period. For example, if 60% of the graduating secondary school students in a specific state historically enroll in state HEIs (HE Institution), then predicting the number of "in-state" enrollments in the next year is simply $F_{t+1} = 0.6Z_t$ where Z_t is the number of "in-state" secondary students graduating, and F_{t+1} is the projected number of "in-state" students entering state HEIs.

Another example is from Burkett (1985), who used a cohort-survival model to forecast freshman enrollment at the University of Mississippi during 1985–1989, based on historical data of grade 7–12 secondary school students, high school graduates in the state of Mississippi, the University of Mississippi freshman enrollment, and the number of out-of-state freshmen. The historical survival ratios were calculated based on the historical data to forecast freshman enrollment. As detailed in Appendix 1, others who used cohort-survival methods in the context of HE include Schmid and Shanley (1952), Murtaugh et al. (1999), Min et al. (2011), Trusheim and Rylee (2011), Tsevi (2018), and Wade (2019).

(b) **Markov** analysis has the advantage of being relatively straightforward to set up and does not require extensive use of computers to find output parameters like steady-state probabilities. A Markov system is based on a system with K possible states and transition probabilities for elements moving from one state to another during one period, where P_{ij} is the probability of moving from state i to state j.

Bessent and Bessent (1980) used Markov analysis on the progression of doctoral students, from year to year, through their degree program, based on past years' average percentages. Kwak et al. (1986) extend the approach to a trimester-based institution by modeling each trimester separately. They captured graduation rates and the number of enrolled students relatively accurately for the department studied. Later, Shah and Burke (1999) presented a Markov analysis of undergraduate students as they progress towards their degree. Their model takes into consideration the course of study and the gender and age of the student when starting the degree program. They were interested in predicting the average time to degree completion. As shown in Appendix 1, others also used Markov analysis, including Hwang et al. (1998), Nicholls (2009), Allen (2013), Witteveen and Attewell (2017), and Sass et al. (2018).

5.2.3 Regression Analysis

A regression model is a causal model that detects relationships between the variable to be forecasted (dependent variable) and another given explanatory variable. Multiple regression deals with multiple explanatory variables. Nonlinear regression and econometric models (several simultaneous equations where the "dependent" variable of one equation may become an explanatory variable in another equation) are hardly used in HE forecasting—they are used more by macro-economists. Regression analysis is widely used by researchers in HE, but mostly not for forecasting purposes—often regression is used for pedagogical research. Regression is also used as sub-method in data mining (see Sect. 5.2.5). Regression modeling is one of the most popular forecasting methods in HE and in general (see Sect. 5.4.1). Here are the two main regression models used in HE:

(a) **Simple regression** model mostly assumes a linear relationship of the forecasted variable (e.g., enrollment) with another explanatory variable, for example, $F_{t+1} = a + b(t + 1)$ where the time $t + 1$ is the explanatory variable and F_{t+1} is the forecast in period $t + 1$.
(b) **Multiple regression** in HE, forecasting is often linear: the forecasted variable, F_{t+1}, has several explanatory variables, $F_{t+1} = a + \sum_{j=1}^{t} b_j X_j$ For example, Sinuany-Stern (1984) used a student questionnaire to verify explanatory variables for projecting the numbers of students in each of the three campuses of a large community college in Cuyahoga Community College (Ohio), utilizing a multiple linear regression model for the change in enrollments from 1 year to the next 2 years. The predictors of the regression model were: the unemployment rate in the county, the dollar amount allocated to financial aid, the opening of a new facility on the campus, and the number of high school graduates from the campus's draw area. The predictors were based on the market research questionnaire (although at that time, the administrators of the college refused to use the term marketing!). In a second stage, the past breakdown to sub-categories, as needed for the state budget funding formula, was predicted via the ratio model; the ratio was predicted by utilizing the average past breakdown percentages, using moving average.

As shown in Appendix 1, others also used multiple regression analysis in HE, including Baisuck and Wallace (1970), Sinuany-Stern (1980), Sinuany-Stern

(1984), Sinuany-Stern and Yelin (1993), Murtaugh et al. (1999), Amber et al. (2015), Sweeney et al. (2016), Chou (2019), and Wade (2019).

5.2.4 Simulation Models

Simulation is one of the most popular methods used in forecasting (as shown in Sect. 5.4.1); it is a model which imitates a system or a process behavior to learn about the system over time, sometimes to improve it. It allows one to conduct virtual experiments or to test behavior under various scenarios. Simulation models can consist of mathematical equations or series of relations between various components and are mostly computerized. The simulation is a proxy of the real system—it cannot capture the full capacity of the real system due to its complexity and the lack of information available about it. In the context of HE, simulation is used mostly for planning and forecasting—pedagogical simulators and games are not considered here at all. As shown in Appendix 2 (items 15–18), the main three simulation sub-methods are:

(a) System dynamics (SD) is a deterministic continuous model utilizing differential equations to describing the interaction among the subsystems.
(b) Discrete event simulation (DES) is a stochastic model advancing time by events or by discrete-time interval follow-up of the system state and its stochastic movement over time.
(c) Agent-based simulation (ABS) is an extension of DES for several processes/agents with various behaviors which interact with each other.

In 1970, Baisuck and Wallace were already using a simulation approach for enrollment projection in various types of HEIs: private universities, public universities, community colleges, and statewide planning activity. The model takes sub-groups of students and their movements within the HEI over time, using a regression model which estimates the changes in each group as a function of some other planning variables. Xiao and Chankong (2017) used SD simulation for predicting the supply and demand of medical education talents in the Jiangsu region of China. They predict the number of doctors needed to maintain the average levels of 34 OECD countries by the year 2024. The forecast allows HE authorities to make adjustments to meet the additional demand for Medical Doctors needed. They claim that the SD model is applicable to other regions in China (ibid.). SD encompasses the complexity of the system, while other methods focus on parts of the problem. As shown in Appendix 1, Saltzman and Roeder (2012) also used simulation in HE.

5.2.5 *Data Mining (DM)*

Since the late 1990s, DM has been used more and more as a forecasting method in HE (see Sect. 5.4.1). DM combines computer science, statistics, and analytics. DM uses various old and new forecasting and classification algorithms, amongst which are linear modeling, regression, correlation, decision trees, random forests, density estimation, probabilistic graphical models, neural networks, nearest-neighbor, variance analysis, text mining, principal components analysis (PCA), time mining, association rule, hierarchical clustering, density-based methods, and others which are being added over time. DM automatically tests a variety of methods on a big database and selects the method which fits best. There are several DM toolkits, such as SPSS Clementine (https://softadvice.informer.com/Spss_Clementine_12.0_Free_Download.html assessed on Nov. 2020) that specialize in DM. Main DM steps are data preparation, visualization, prediction (e.g., regression, neural network, time series) or classification/clustering (e.g., random forest, PCA), and selecting the best model. Data source in HE can be from institutional database, web-based (e.g., from online course), and questionnaire.

During the last 20 years, DM has been used very often, mainly to improve teaching practices for both the learning process and the learners (to improve student retention), or to identify what type of courses or other managerial actions may decrease students' chances of dropping out of a course or the college, thus increasing internal enrollments (by retention), rather than passively trying to predict enrollments as dictated by internal or external forces to be revealed via traditional forecasting methods. As shown by educational data mining (EDM), based on the HEI database of student achievement by course performance over the semester, the retention of each student in a course, or in a given semester can be predicted—as big data analysis improves over the years—see literature review on Educational Data Mining (EDM) by Romero and Ventura (2007), covering 304 articles up to 2005. They pointed that data mining techniques can be classified as follows: statistics and visualization; clustering, classification, and outlier detection; association rule mining and pattern mining; and text mining. The Journal of Educational Data Mining started in 2009—its first article was a review of the literature on EDM by Baker and Yacef (2009)—noting the increased emphasis of EDM on prediction, they covered 45 most cited articles published during 1995–2009. In the context of EDM, Siemens (2013) introduced the term learning analytics as data analytics in education *"...to increase the scope of data captured so that the complexity of the learning process can be more accurately reflected in analysis."* He points at the issue of privacy and data ownership, and ethics in EDM in general and learning analytics in particular (ibid.). Additional literature reviews have been published on EDM: Al-Razgan et al. (2014), who covered over 300 EDM articles published during 2006–2013; and Shahiri et al. (2015), who reviewed 39 articles, about predicting student performance using DM techniques during 2002–2015. Recently, Romero and Ventura (2020) extended their past review to include a wide range of new terms used during the last ten years in EDM and learning analytics: academic analytics, institutional analytics, teaching analytics, data-driven education, data-driven decision-making in education, Big Data in education, and educational data science. Hellas et al. (2018) reviewed 357 articles on EDM, highlighting the use of DM for predicting the performance of students in HE. There are more reviews of EDM. Here are few examples on the use of DM in HE in Appendix 1 by Jantan et al. (2010), Miguéis et al. (2018), and Sweeney et al. (2016).

Here are some details on several DM sub-methods:

(a) **Decision tree** is a structure that aids decision-makers in presenting options with their consequences and probabilities. In data mining, there are classification trees for discrete sets of values and regression trees with continuous variables. Hamsa et al. (2016) used a decision tree in a prediction model of student academic performance.
(b) **Random forests** are an ensemble learning method for classification. They utilize regression and other tasks that operate by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes (classification) or mean prediction (regression) of the individual trees. Hasan et al. (2020) used analytics and DM techniques to predict student performance in HEIs using video learning (dichotomy: success = 1, failure = 0). The sample included 772 students who registered for e-commerce courses on video. Data was retrieved from the student information system, learning management system, and mobile applications. DM was used to explore eight models and to reduce the number of parameters, transformations were used, including PCA. The results showed that the random forest accurately predicted successful students at the end of the class. Sweeney et al. (2016) used factorization machines, a random forest, and personalized linear regression to predict students' grades in the next semester and improve student performance and retention in the USA. Moon et al. (2018) used time series analysis and a random forest to forecast university buildings' electrical loads in Korea.
(c) **Neural networks** are nonlinear statistical data modeling or decision-making tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. For example, Aladag et al. (2010) used neural networks. As described above, the method was applied to enrollments at the University of Alabama.
(d) **Genetic programming** is a heuristic technique to search for an optimal program among the space of all programs. For example, Amber et al. (2015) used genetic programming and multiple linear regression models to forecast electricity consumption in a UK university. The genetic programming model performed better than the multiple regression model.
(e) **Grey model** combines the theoretical structure of the forecasting model with data to complete the model, for example, combining linear regression with a neural network. Tang and Yin (2012) used grey predictions and exponential smoothing for education expenditure and school enrollment, using univariate time series data from the Chinese National Center for Education Statistics. Based on several methods for fitting the forecast, such as mean-squared error,

they concluded that the two grey models they used outperformed exponential smoothing. They concluded that their results provide a basis for further research in model-building for the short-term prediction of student enrollment and education expenditure. Along these lines, Ge and Xie (2015) applied a grey forecasting model based on improved residual correction to university education cost prediction in China.

5.2.6 Questionnaires and Surveys

Questionnaires and surveys are used as an aid to forecasting with one of the above-mentioned methods, often with regression or DM. The questionnaire is the set of questions distributed to a certain group; in HE, it might be students, faculty, staff, etc. A survey is not necessarily a questionnaire; it can be data from internal or external sources, often combined with some analysis. In this category, qualitative methods are imbedded such as experts, Delphi (a specific procedure for questionnaire with feedback). Questionnaires were very popular in HE and the social sciences in general, in which researchers make use of questionnaires, not necessarily for forecasting but to understand people's behavior or the success of various teaching methods, etc.

In the past, administrators tended to use surveys—such as collecting comparable data from other HEIs—rather than questionnaires. For example, Edwards performed a survey in 1932, collecting data on college enrollment from 96 US Colleges over the period 1890–1930, during times of economic depression, to verify whether there was evidence of an enrollment increase because of the depression. Sinuany-Stern (1976) used questionnaire results to verify reasons for the 20% growth in student enrollments at a community college in Ohio. Based on the results of the questionnaires, a multiple regression model was utilized for predicting enrollments for that college. Banerjee and Igbaria (1993) used questionnaires to plan computer capacity in 170 US universities.

Since the mid-1980s, marketing became more and more acceptable in HE. Questionnaires and surveys are often used for HE marketing, as shown in the literature review of marketing in HE by Hemsley-Brown and Oplatka (2006). Marketing has become a reality in HE over the past 25 years, despite the ethical arguments surrounding marketization—as presented in the latest review of the literature by Oplatka and Hemsley-Brown (2021). The questionnaire/survey may reveal what motivates students to enroll (or alumnae to donate), pointing towards actions and policies that management can take to increase enrollment, such as advertisements and public relations in various media.

In the context of forecasting enrollments, the marketing approach is designed to allow control at the enrollment level by taking actions such as advertising to increase enrollments, or to achieve enrollment targets set by administrators.

5.3 Types of Classifications of Forecasting Methods in HE

In the context of enrollment forecasting, both DM methods and questionnaires for market research represent *active forecasting methods*, where the main purpose of the administrators is to maximize enrollments by performing some actions based on these methods, rather than providing a *passive forecast*, as was the case until the 1990s. While DM mostly utilizes internal databases from the institution, market research often creates new information based on questionnaires or surveys. Barthwal (2000) also used the terms active and passive forecasts (pp. 112–113), but more in the sense of an unchanged environment in the passive forecast versus the dynamic environment in the case of an active forecast.

We introduce the terms *active* and *passive* forecasting methods in a slightly different sense. We describe forecasting as *active* when it provides a control for the administrator by pointing at some actions for influencing future events, while a *passive* forecast assumes no such control. The two leading forecasting approaches, DM and marketing are *active* forecasting methods, pointing the administrators at actions to be taken to achieve a targeted forecast. Regression analysis and simulation are not always *active* forecasting methods. However, time series and ratio methods are *passive* forecasting methods.

5.3.1 New Classification: Active Versus Passive Forecasting Methods

As explained above, we suggest to classify the six main groups of forecasting methods in HE (Sect. 5.2) into two groups:

(a) ***Passive forecasting methods***: (1) *Time series* (2) *Ratio methods*
(b) ***Active or passive forecasting methods****:* (3) *Regression* (4) *Simulation*
(c) ***Active forecasting methods****:* (5) *Data mining* (6) *Questionnaires and quantitative*

Other characteristics of each of the six main forecasting methods are as follows.

1. *Time Series*: Some sub-methods are deterministic (moving average and exponential smoothing); some sub-methods are stochastic/probabilistic (ARIMA). Time series, basically, are not causal methods.
2. *Ratio Methods*: Cohort-survival is a deterministic method, while Markov analysis is a stochastic model. Ratio methods are not considered causal, although a causal relationship is imbedded in the choice of groups.
3. *Regression Methods:* Are stochastic but not always controlled variables.

4. *Simulation*: System dynamics is a deterministic method, while discrete event simulations and agent-based simulations are usually probabilistic. Causality is often assumed, though not always.
5. *Data Mining Methods*: Some are deterministic, and some are stochastic, some are casual, and some are not; some are predicting a continuous level (e.g., enrollments), and some are predicting classification-success or failure.
6. *Questionnaires and Surveys*: Used, often, in conjunction with some of the above methods.

5.3.2 Other Classifications of Forecasting Methods

There are other classifications of forecasting methods, in general, not specific to HE. Here are two examples:

Makridakis et al. (1983) full classification is the most general:

(a) Smoothing and decomposition: Average methods, and exponential smoothing, decomposition, ratio-to-moving average, census decomposition
(b) Regression and Econometric: simple regression, multiple regression, econometric models
(c) Box-Jenkins ARIMA: Box-Jenkins, multivariate time series
(d) Qualitative methods: predicting cycle, qualitative, and technological method

Another example for classification method is by Armstrong and Green (2018), who foster conservatism as a golden rule in forecasting and simplicity, suggest another breakdown for two types of forecasting methods:

(a) Judgmental methods, including prediction markets, multiplicative decomposition, intention surveys, expectation surveys, expert surveys, simulation interaction, structured analogies, experimentation, and expert systems.
(b) Quantitative methods, including extrapolation, rule-based methods, judgmental bootstrapping, segmentation, simple regression, and knowledge models.

Combining forecasts from several methods is recommended, as it has a high potential to reduce forecast error (ibid.).

The breakdown of forecasting methods of Armstrong and Green (2018) and its terminology and sources better fit market research (Market/marketing was mentioned 42 times in the article, including in 13 marketing references). Indeed, marketing (marketization) became accepted in HE during the past 30 years (Oplatka & Hemsley-Brown, 2021).

The third classification method Brinkman and McIntyre (1997) classified forecasting methods in HE, divided into three main categories as follows:

(a) Quantitative methods: (1) curve-fitting techniques: trend analyses, enrollment ratio, moving average, autoregressive integrated moving average (ARIMA), exponential smoothing, seasonal models, regressing on time. (2) Causal explanatory methods: multiple regression, Markov, ratio, and flow models (e.g., cohort-survival)

(b) Qualitative methods: Experts and Delphi

(c) Combined approaches

Their literature review was based on applications of the forecasting methods above in HE, covering articles from 1980 to 1995 (ibid.). Almost all the above-listed methods were based on classical textbooks such as Makridakis et al. (1983) and Hyndman and Athanasopoulos (2018). Brinkman and McIntyre (1997) is not as detailed as the classical textbooks on forecasting, added methods specific to HE; namely, Ratio method, cohort-survival, and Markov system. We added another two forecasting approaches: DM (educational DM–EDM and learning analytic) and questionnaires/surveys (for marketing HE). Moreover, our classification is based on active and passive forecasting.

5.3.3 Managerial and Planning Aspects of Forecasting

Linking enrollment predictions and tuition income models is common, for example, by Trusheim and Rylee (2011) for the University of Delaware. The enrollment matrix is constructed from past enrollment data by semester over several years by type of entering students (freshman, transfer, readmitted, and continuer). The model is based on a *cohort-survival method*. The predicting model consists of four steps: (1) collect historical data on enrollment by full-time and part-time ratios; (2) develop the retention percentage for continuing students; (3) obtain new freshman, transfer, and readmitted student targets for future semesters; and (4) run the numbers through the model to generate predictions. The prediction is based on average historical percentages for each group, where the head of the university can dictate a total target. The tuition model was integrated, where the enrollment breakdown of full-time/part-time ratio by resident/non-resident ratio was used for calculating the desired income from tuition based on the full-time tuition versus part-time tuition, and resident tuition versus the higher non-resident tuition. The desired ratios are transmitted to the admission office to consider in their admission process. This model is a good example of how the policy of HEIs can affect enrollment and the income from tuition.

The level of detail in the forecast varies from one application to another, and the horizon of the forecast needed also varies among applications. If there is high demand for a specific HEI, the institution does not need to forecast enrollment but to determine a target number for its enrollment according to other parameters which need to be predicted (e.g., income, faculty, space, etc.). Yet, fluctuations may in fact occur in actual enrollments.

Breakdowns of student enrollments by discipline, by gender, and by other demographic parameters to plan the resources needed for each group are essential. The forecast can be from the top down, where first the total number of students is calculated by a specific method, and then the total is broken down into its components in a second stage by making some assumptions about percentages (based on past breakdowns) within the total enrollment forecasted. Another approach is a forecast from the bottom up, by using various methods to forecast the enrollment of each group under various assumptions and then summing up those groups' forecasts to obtain the total student enrollments.

Hoenack and Weiler (1979) present a university (Minnesota) total enrollment forecasting model in a situation where enrollment may be less than the university capacity and may decline due to a reduction in the size of the traditional college-going population and the labor market situation. In their specific situation, the state allocation to a public university was based on enrollment forecasts for the university; thus, predicting lower than actual enrollment caused a reduced state allocation to the university that year. The comprehensive model was composed of ten sequential equations, which were simulated sequentially within each year and over the years. Each equation predicts a specific subgroup at time t as a function of other relevant sub-groups and demographic (e.g., cohort) and economic parameters (some lagged), such as tuition, unemployment rate, salaries of college and non-college graduates.

Forecasting accuracy is an important issue. The main method for evaluating forecast accuracy is mean-squared error of their past observations versus their forecast—the smaller the better (Makridakis et al., 1998). Another less frequently used method is mean absolute error (ibid.). Combining forecasts is often done to achieve greater accuracy (Armstrong & Green, 2018).

There is not a widely accepted best forecasting method in general, and specifically in HE for forecasting university enrollment or income, or other parameters needed for HE planning. Furthermore, many of the existing methods require the knowledge and use of advanced statistical/mathematical techniques. Many HEIs do not have administrative staff with the expertise to utilize advanced statistical methods. The simple methods are often less accurate than the more advanced methods, but not necessarily. Many HEIs hire consultants for this purpose (such as the author of this chapter). It is important that the consultant has proficiency in a wide range of forecasting methods and access to forecasting software.

5.4 Counting Number of Articles on Forecasting in HE by Method and by Area

Since there are thousands of articles on forecasting methods in HE, it was too much to review each; thus Appendix 1 presents only examples of articles to present the various forecasting methods and what they were used for. However, the number of articles published on forecasting methods in general, versus HE was counted here, as taken from the Web of Science (WoS) during 2000–2020, as shown in Appendix 2. In total, there are over 5000 articles on forecasting in all 30 methods listed in

Appendix 2. Similarly, looking at the 11 areas of application in Appendix 3, where forecasting is used in HE, a total of about 14,500 articles were found.

5.4.1 Counting Number of Articles on Each Forecasting Method in HE

Column-1 of Appendix 2 presents, for each of 30 listed forecasting methods (and their synonyms), the number of articles for which the method appeared in their topic (i.e., in the title or abstract or keywords of the article) in general (not necessarily in HE). Since some forecasting methods are used, also, for other purposes besides forecasting, we require that in the search engine for HE, in addition to specific forecasting methods, the word forecast (or some synonym) will appear, too. The total sum of articles in column-1 is almost 6 million articles. The four leading forecasting methods in general, with the maximal numbers of articles, are simulation (with its sub-methods 15–18) with over 2.6 million articles; data mining (with its sub-methods, 19–29) with over 1.68 million articles, regression with over 0.887 million articles, and questionnaires with over 0.447 million articles.

Column-2 of Appendix 2 presents, for each of 30 forecasting methods, the number of articles where the word “forecast” and the word “higher education” and the method (or their synonyms) appear in the topic of the article. The forecasting methods with the highest numbers of articles are as follows.

(a) Regression, with over 26,000 articles
(b) Simulation or its sub-methods (15–18), with about 22,000 articles
(c) Data mining or its sub-methods (19–29), with about 20,000 articles
(d) Questionnaires with 11,000 articles

Column-3 counts the number of articles where the method is in the topic, and HE and forecast or their synonyms appear in the title of the article. The sum of the articles over the 30 forecasting methods is 5219, obviously, less than columns 1 and 3. In this case, again the same four methods forecasting methods are leading but in different order: questionnaires have the largest number of publications, with 2849 articles; regression is second, with 969 articles; and data mining (with its sub-methods: 19–29) is third, with 843 articles; simulation (with its sub-methods 15–18) is the fourth, with 407 articles. For HE, it is more reasonable to take column 2 counting as representing, since HE applications tend not to highlight the specific type of the methodology in the title of the article but rather in the abstract or keywords.

In summary, the same four methods in the first three columns, in different orders, are leading in number of articles: regression, simulation, data mining, and questionnaires.

5.4.2 Counting Number of Articles in HE, and Forecasting, by Main Areas of Application

Appendix 3 counts in WoS the numbers of articles in each of the 11 listed application areas. The leading areas in column-1 are marketing, performance, transportation, and teaching.

The leading areas in column-2 of Appendix 3, where HE forecasting and the area of application appear in articles' topics, are as follows:

1. Marketing, with about 90,000 articles
2. Teaching, with about 52,600 articles
3. Enrollment, with about 46,000 articles
4. Performance, with about 38,700 articles

In column-3 of Appendix 3, where HE and forecasting appear in articles' titles, and the area appears in the topic, there are the same four leading areas of application as in column-2, but in a different order: enrollment with 3484 articles, marketing with 3149 articles, teaching with 2379 articles and performance 1712 articles.

In Appendix 3, the total number of articles with *area in HE* in their *topic* versus *title* (columns 2 vs. 3) as a percent from the total number of articles with *area* not necessarily in HE (column 1) is 1.69% versus 0.077; this is similar to the parallel percent of total number of articles with HE and *forecasting* method in their *topic* versus *title,* 1.416% versus 0.087% (Appendix 2 last two columns in relation to columns 2 and 3).

Obviously, for Appendices 2 and 3, the relation between the first three columns is the same: column-3 articles are included in column-2 articles, and column-2 articles are included in column-1 articles. Regarding the exact number of articles, where each method/area was used in HE for forecasting, column-2 numbers can be considered as a proxy for the upper bound number of the articles (for each forecasting method and area of application); while column-3 can be considered as proxy for their lower bound. Proxies in each column mean that there might be double counting of the same article (e.g., once in data mining, and another time in regression, as a sub-method in data mining) or missing synonyms for some methods.

5.5 Summary and Conclusions

This chapter reviews many forecasting methods used in HE, and their main areas of application, with examples drawn from the literature (in Appendix 1). By counting the number of articles published in the Web of Science over the last 20 years, we found that four forecasting methods were used most often in forecasting in HE: regression, simulation, DM (including its sub-methods), and questionnaires (for marketing purposes). Furthermore, four areas of application were used most often for forecasting in HE: enrollment, marketing, teaching, and performance.

The new upcoming forecasting method during the past 20 years is DM and its sub-methods: both old methods (e.g., regression) and new methods (e.g., genetic algorithms). DM selects the best from several methods applied to the data. Often, Educational DM (EDM and another variation—learning analytics) is, often, used as a tool to increase student retention from one semester to the next. Moreover, DM can handle big data to predict if a single student will drop out, and the reason, so that the administration/lecturer is able to take actions to retain the student before s/he drops out. EDM and learning analytic combine many aspects of forecasting applied specifically to HE.

In addition to the classical use of questionnaires by theoretical researchers in education to study various phenomena in HE, administrators are using questionnaires more often in the past 20 years, mainly for market research—to figure out ways to increase enrollments or to influence the university's ranking and its components, to increase the university's attractiveness for potential students.

We introduce the terms *active* and *passive* forecasting methods in a new sense. *Active* forecasting provides a control for the administrator by pointing at some actions to influence future developments, while a *passive* forecast assumes no control. The two leading forecasting approaches, DM and marketing, are *active* forecasting methods, pointing administrators at actions to be taken to achieve a targeted forecast. Regression analysis and simulation are not always *active* forecasting methods. However, time series and ratio methods are *passive* forecasting methods.

For future research, the counting performed here is a rough proxy, improving the synonyms used can give more accurate counting.

Appendix 1

Forecasting in Higher Education: Summary of Selected Applications over Time

Name of first Author (year)	Forecasting method type	Area of application	Organizational level	Country
Edwards (1932)	Survey	Enrollment forecast	University	USA
Schmid and Shanley (1952)	Ratio and cohort-survival	Enrollment projection	University	USA
Baisuck and Wallace (1970)	Simulation and regression	Student enrollment	University and state levels	USA
Sinuany-Stern (1976)	Multiple regression models	Questionnaire on reasons for students enrolling	Multi-campus community college	USA
Hoenack and Weiler (1979)	Ten sequential equations	Total forecast: undergraduate enrollment	University	USA
Sinuany-Stern (1980)	Multiple regression and ratio	Students by year and level	Total and each state's university	USA Indiana
Bessent and Bessent (1980)	Markov analysis	Students' progression by year	Department, by year of study	USA
Sinuany-Stern (1984)	Multiple regression and ratio method	Enrollments and costs for budgeting	Multi-campus community college	USA
Burkett (1985)	Cohort-survival ratio	Freshman enrollment prediction	University	USA
Kwak et al. (1986)	Markov analysis	Student enrollment	University	USA
Banerjee and Igbaria (1993)	Questionnaire/ survey	Computer capacity planning	National	USA and Canada
Sinuany-Stern and Yelin (1993)	Regression	Hardware resources (CPU, memories, etc.)	University	Israel
Hwang et al. (1998)	Fuzzy time series versus Markov, and first-order time-variant model	Forecasting student enrollment	University	USA
Murtaugh et al. (1999)	Cohort-survival, proportional hazards and regression	Students retention probabilities	University	USA

Shah and Burke (1999)	Markov analysis	Undergraduate student progression	National	Australia
Chen (2008)	ARIMA	Enrollment forecast	University	USA
Nicholls (2009)	Markov models	Planning and benchmarking doctoral progression	University	Australia
Aladag et al. (2010)	Neural network, fuzzy time series–DM	Forecast of enrollment	University	USA
Jantan et al. (2010)	Data mining	Prediction of academic talent	National	Malaysia
Min et al. (2011)	Cohort-survival, nonparametric survival analysis	Student graduation	9 HEIs, 19 years	USA
Trusheim and Rylee (2011)	Cohort-survival, percentages by type of student	Enrollment prediction and tuition income	University	USA
Lavilles and Arcilla (2012)	Simple moving average, exponential smoothing	Student enrollment in electronic courses	By e-course, within a university	USA
Saltzman and Roeder (2012)	Simulation	Student flow, and enrollment to colleges	College of business	USA
Tang and Yin (2012)	Grey models better than exponential smoothing–DM	Education expenditure and student enrollment	National	USA
Agboola and Adeyemi (2013)	Ratio method and fixed annual %	Faculty and student forecast	National	Nigeria
Allen (2013)	Ratio model and Markov model	Enrollment projection at various levels	University and discipline	USA
Ge et al. (2013)	Fuzzy time series and exponential smoothing	Enrollment	University	USA
Amber et al. (2015)	Multiple regression, genetic algorithm–DM	Electricity forecasting	National	United Kingdom
Ge and Xie (2015)	Adaptive residual correction based on Grey model–DM	Forecasting cost of university education	University	China

(continued)

(continued)

Name of first Author (year)	Forecasting method type	Area of application	Organizational level	Country
Anggrainingsih et al. (2015)	Exponential smoothing and time series	Predicting # of website visits	University	Indonesia
Pamungkas and Rofiqoh (2015)	Moving average	Enrollment	University	Indonesia
Sweeney et al. (2016)	Factorization machines, random forest and personalized linear regression–DM	Retention in next-term, grade prediction to improve student performance	National	USA
Hamsa et al. (2016)	Decision tree and fuzzy genetic algorithm–DM	Student academic performance prediction	BS and MS students of computer science	India
Cohen (2017)	Data mining classification	Predicting course dropout	Individual student	Israel
Witteveen and Attewell (2017)	Hidden Markov models	Students graduation	National	USA
Xiao and Chankong (2017)	System dynamics	Forecast of demand and supply of students (medical talents)	National	China
Miguéis et al. (2018)	Data mining	Students' academic performance	University	European country (details not mentioned)
Moon et al. (2018)	Time series analysis, random forest–DM	University building electrical load forecast	University	Korea
Sass et al. (2018)	Bayesian structural equation model, Markov, Monte Carlo samples, factor analysis–DM	Student retention	University	USA
Tsevi (2018)	Cohort-survival, qualitative study via interviews, using the theory of persistence	International students' success	University	USA

Chen et al. (2019)	Time series analysis	Student enrollment	University	USA
Wade (2019)	Cohort survival, random and fixed effects models, linear regression	Student retention rate	National	USA
Chou (2019)	Questionnaire and regression	Predicting self-efficacy in English test preparation	National	Taiwan
Hasan et al. (2020)	Analytic and data mining, random forest	Predict student performance in video e-course	Course	Malaysia

Appendix 2

Number of articles on forecasting[a] in higher education (HE[a]) by method

No.	Method	Number of articles during 2000–2020			Percentage of:	
		Method in topic[b] (1)	Method, forecast [a] and HE [a] in topic[b] (2)	Method in topic[b], forecast [a] and HE [a] in title (3)	Column (2) from (1)	Column (3) from (1)
1	Ratio method	3378	20	0	0.592	0.000
2	Cohort survival	222	4	0	1.802	0.000
3	Survival analysis	31, 779	787	12	2.476	0.038
4	Markov	116, 354	822	19	0.706	0.016
5	Sequential equations	4	0	0	0.000	0.000
6	Time series	161, 813	2100	67	1.298	0.041
7	Trend analysis	8732	106	3	1.214	0.034
8	Moving average	14, 359	267	13	1.859	0.091
9	Exponential smoothing	1738	70	6	4.028	0.345
10	ARIMA	5464	158	11	2.892	0.201
11	Auto regression [a]	30, 492	364	17	1.194	0.056
12	Fuzzy time series	680	146	3	21.471	0.441
13	Regression [a]	887, 584	26, 621	969	2.999	0.109
14	Linear modeling	1798	27	0	1.502	0.000
15	Simulation	2, 280, 840	19, 565	330	0.858	0.014
16	System dynamic [a]	23, 929	360	28	1.504	0.117
17	Discrete event [a]	294, 444	2210	47	0.751	0.016
18	Agent-based simulation	3840	54	2	1.406	0.052
19	Data mining	66, 410	2724	193	4.102	0.291
20	Neural networks	166, 709	3804	137	2.282	0.082
21	Decision trees	23, 178	1097	84	4.733	0.362
22	Random forests	6088	210	10	3.449	0.164

23	Bayesian	143,585	1798	59	1.252	0.041
24	Analytic [a]	189,999	3013	179	1.586	0.094
25	Genetic	1,015,427	6173	119	0.608	0.012
26	Grey	51,412	623	39	1.212	0.076
27	Density estimation	9879	50	0	0.506	0.000
28	Knowledge discovery	9123	361	20	3.957	0.219
29	Mapping study	1819	49	3	2.694	0.165
30	Questionnaire	447,487	11,361	2849	2.539	0.637
	Total methods	5,998,566	84,944	5219	1.416	0.087

Search was performed in Web of Science for 2000–2019 (in September 2020)

[a]Synonyms used for forecasting: forecast, prediction, predictive, predicting, predict, projection, projective, projecting, forecast; and higher education: academic college, university, "tertiary education;" and (auto regression: autoregression, autoregressive; or linear regression: multiple regression, regression; or system dynamic: systems dynamic, system dynamics; or discrete event: Monte Carlo, DES; or analytic: analytics)

[b]Topic means that the search words appear in the article's title, abstract, or keywords

Appendix 3

Number of articles on forecasting[a] in higher education[a] by area of application

No.	Area of application	Number of articles during 2000–2020			Percentage of:	
		Area in topic[b] (1)	Area, forecast [a] and HE [a] in topic[b] (2)	Area in topic[b], forecast [a] and HE [a] in title (3)	Column (2) from (1)	Column (3) from (1)
1	Transportation	2, 687, 092	32, 053	1318	1.193	0.049
2	Industry	1, 535, 172	24, 964	846	1.626	0.055
3	Transfer of knowledge	224, 253	5056	208	2.255	0.093
4	Marketing	7, 730, 644	90, 043	3149	1.165	0.041
5	Projection	274, 406	13, 867	439	5.053	0.160
6	Enrollment	697, 521	45, 926	3484	6.584	0.499
7	Faculty	217, 093	14, 531	756	6.693	0.348
8	Teaching	1, 803, 689	52, 620	2379	2.917	0.132
9	Student performance	6366	766	107	12.033	1.681
10	Performance	3, 565, 201	38, 688	1712	1.085	0.048
11	Retention	249, 534	2378	175	0.953	0.070
	Total areas	18, 990, 971	320, 892	14, 573	1.690	0.077

Search was performed in Web of Science for 2000–2019 (in September 2020)

[a]Synonyms used for forecasting: forecast, prediction, predictive, predicting, predict, projection, projective, projecting, forecast; higher education: academic college, university, "tertiary education"

[b]Topic means that the search words appear in the article's title, abstract, or keywords

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Chapter 6
Survey of Methods for Ranking and Benchmarking Higher Education Institutions

José-Luis Pino-Mejías and Pedro-Luis Luque-Calvo

Abstract The objective of this chapter is to provide managers and leaders of Higher Education Institutions (HEI) with the knowledge that allows them to evaluate the possibilities and limitations of rankings and benchmarking techniques, and how these techniques can be applied correctly in the different levels of higher education systems.

The chapter includes a presentation of six of the most known international university rankings, a selection of multicriteria decision-making techniques necessary to select the variables to be used, normalize their values, determine their weights, choose the aggregation method and measure how the position of each institution in the ranking depends on the methodological options adopted. For each technique, examples of application to HEI are shown.

The HEI benchmarking interactive tool (HEIBIT), a tool developed to facilitate learning these techniques in international postgraduate programs in the management of HEI in Colombia, Cuba, Dominican Republic, Ecuador, and Spain, is also presented.

Keywords Higher education · Rankings · Benchmarking · Efficiency · Multiple criteria · PROMETHEE · Data envelopment analysis · Sensitivity analysis · Uncertainty analysis

6.1 Introduction

Universities play a significant role in the development of societies; therefore, measuring and assessing their performance becomes crucial for various stakeholders, including government, industry, and society (Olcay & Bulu, 2017).

J.-L. Pino-Mejías (✉) · P.-L. Luque-Calvo
Departamento de Estadística e Investigación Operativa, Universidad de Sevilla, Seville, Spain
e-mail: jlpino@us.es

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Among the different instruments of quality assessment in higher education, rankings probably attract the most public attention. Rankings (or league tables) are a key element in shaping the opinions of students, parents, and employers about the quality of Higher Education Institutions (HEIs) (Marmolejo, 2016). In recent years, rankings of HEIs have increased, and their usage has expanded. Currently, it is common for HEI managers to resort to these when making important decisions or managerial policies (Johnes, 2018). In the first section, we describe six of the most known international university rankings, using the information from their websites.

Relative performance evaluations or benchmarking is the systematic comparison of the performance of one organization against other organizations (Bogetoft & Otto, 2011). The interest in the benchmarking of HEIs has increased in parallel to the development and dissemination of university rankings (Moed, 2017).

The results of any public evaluation always influence the reputation of the units on which they are carried out. In addition, they have a special importance when they are used to carry out the institutional evaluation or to establish financing of those units. Therefore, the managers of universities and evaluation agencies must know the possibilities and limitations of each technique used in the evaluation processes.

Ranking and benchmarking are based on the use of techniques developed in the field of multicriteria analysis, and specifically, efficiency analysis when inputs and outputs are considered.

The first element in any multicriteria analysis is the criteria selection. At this stage, the theoretical framework that guides the selection of the criteria according to the objective of the classification, or the benchmarking, must be explicit and allow selecting the indicators that will be used to measure the characteristics that they seek to represent in their classifications. However, in practice, compilers are restricted by the limited availability of comparable and verified data. Because "quality" and "excellence" are difficult to define and judge, one could argue that the classification tables indicate what can be measured instead of measuring what counts (Locke et al., 2008).

6.2 International Rankings of Universities

World university rankings, such as Academic Ranking of World Universities (ARWU, 2018), Times Higher Education World University Rankings (THE, 2018), Quacquarelli Symonds World University Rankings (QS, 2018), CWTS Leiden Ranking (CWTS, 2018), US News Best Global Universities rankings (USNEWS, 2018) or U-Multirank World University Rankings (U-Multirank, 2018), have in common that they generate controversies about their rigor and are a source of debate. However, in many cases, they act as a guide for public policies that have as an objective to improve the values of the indicators, and the position in the table leagues of universities, colleges, or degrees, without analyzing the real impact on the institutions or in the academic programs.

Table 6.1 Criteria, indicators, and weights of the ARWU Ranking

Criteria	Indicator	Percentage weighting
Quality of education	Alumni of an institution winning Nobel Prizes and Fields Medals	10
Quality of faculty	Staff of an institution winning Nobel Prizes and Fields Medals	20
	Highly cited researchers in 21 broad subject categories	20
Research output	Papers published in Nature and Science (For institutions specialized in humanities and social sciences, the weight of N and S is relocated to other indicators)	20
	Papers indexed in Science Citation Index (SCI)-expanded and Social Science Citation (SSC) Index	20
Academic performance	The weighted scores of the above five indicators divided by the number of full-time equivalent academic staff	10

As an example of indicators used in university rankings, the Academic Ranking of World Universities (ARWU, 2018) compiled annually by the Shanghai Jiao Tong University since 2003 uses the criteria and indicators shown in Table 6.1.

From the ARWU indicators, those who value the Nobel prizes and the Fields medals are the indicators that generate the most discussion; even the best universities in the world cannot be sure if, in the near future, the winners will be their students or professors. For this reason, ARWU calculated in 2014 and 2015 an alternative ranking based on the remaining four indicators, maintaining their respective weights without changes.

From 2012 Shanghai Ranking Consultancy has developed Global Research University Profiles (GRUP), a comprehensive database and benchmarking tool covering 1200 research universities in the world. Based on the data reported by universities and collected from third parties, GRUP presents comparisons of universities in terms of 40 indicators (13 indicators about students, 9 indicators about faculty, 13 indicators about resources, and 5 ARWU indicators).

The Times Higher Education World University Ranking 2019 (THE, 2018) includes more than 1250 universities and uses the 13 performance indicators shown in Table 6.2.

The Quacquarelli Symonds World University Rankings, 2019 (QS, 2018) includes 1000 universities and uses the six performance indicators shown in Table 6.3.

The US News Best Global Universities rankings (USNEWS, 2018) includes 1250 universities and uses the 13 indicators shown in Table 6.4. Results from Clarivate Analytics' Academic Reputation Survey were used to create the two reputation indicators used in US News' ranking analysis.

Table 6.2 Criteria, indicators, and weights of THE Ranking

Criteria	Indicators	Percentage weighting
Industry Income—innovation	Research income from industry (per academic staff)	2.5
International diversity	Ratio of international to domestic staff Ratio of international to domestic students	32
Teaching—the learning environment	Reputational survey (teaching) PhDs awards per academic Undergrads admitted per academic Income per academic PhDs/undergraduate degrees awarded	1564.52.252.25
Research volume, income, and reputation	Reputational survey (research) Research income (scaled) Papers per research and academic staff Public research income/ total research income	19.55.254.50.75
Citations—research influence	Citation impact (normalized average citation per paper)	32.5

Table 6.3 Criteria, indicators, and weights of QS Ranking

Criteria	Indicator	Percentage weighting
Academic Reputation	Reputational survey	40
Employer Reputation	Reputational survey	10
Learning environment	Faculty/Student Ratio	20
Research output	Citations per faculty	20
Internationalization of Faculty	International Faculty Ratio	5
Internationalization of Student	International Student Ratio	5

Examples of rankings that do not obtain a single composite indicator by the weighted sum of the indicators are the Leiden Ranking and U-Multirank. The CWTS Leiden Ranking is based exclusively on bibliographic data from the Web of Science database of Clarivate Analytics (CWTS, 2018); this ranking considers a subset of only the publications in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts and Humanities Citation Index. The CWTS Leiden Ranking 2018 was calculated with the data of years 2013–2016 for each one of the bibliometric indicators shown in Table 6.5.

U-Multirank world university rankings use data from 21 different subject areas and use the performance indicators shown in Table 6.6, which allows comparing universities on the basis of rankings in each subject area rather than looking at the whole institution. U-Multirank does not aim to calculate a ranking of universities or their units but to allow comparison between universities with similar characteristics. The U-Multirank methodology analyzes university scores on individual indicators and places them in five performance groups ("very good" to "weak").

Along with the six methods of ordering and/or comparing the universities mentioned, there is an enormous number of rankings and benchmarking methodologies

Table 6.4 Indicators and weights of US News Ranking

Indicator	Percentage weighting
Global research reputation	12.5
Regional research reputation	12.5
Publications	10
Books	2.5
Conferences	2.5
Normalized citation impact	10
Total citations	7.5
Number of publications that are among the 10 percent most cited	12.5
Percentage of total publications that are among the 10 percent most cited	10
International collaboration	5
Percentage of total publications with international collaboration	5
Number of highly cited papers that are among the top 1 percent most cited in their respective field	5
Percentage of total publications that are among the top 1 percent most highly cited papers	5

Table 6.5 Criterion and indicators of CWTS Ranking

Criterion	Indicators
Research	Number of publications Total and average number of citations, normalized for field and publication year Number and proportion of publications: • That belong to the top k% most frequently cited, with $k = 1,5,10$ and 50 • That have been co-authored with one or more other organizations • That have been co-authored by two or more countries • That have been co-authored with one or more industrial organizations • With a geographical collaboration distance of less than 100 km • With a geographical collaboration distance of more than 5000 km

of world, national or regional scope that allow comparisons of universities and their units, such as degrees, areas, or departments. To designate the institutions or their components that will be evaluated, we will use the term decision-making unit (DMU).

All the rankings are constructed based on a relatively small collection of indicators with which the level of quality of the university can supposedly be measured; as we have seen in the previous examples, they can refer to the missions of the university, teaching, research, or also to other issues such as knowledge transfer, or regional engagement.

The Berlin Principles on Ranking of Higher Education is a set of principles of quality and good practices in HEI rankings approved by the International Ranking Expert Group (IREG, 2006), but actual ranking practices are very different from what the principles propose (Barron, 2017).

Table 6.6 Criteria and indicators of U-Multirank

Criteria	Indicator
Teaching and Learning	Bachelor graduation rate Masters graduation rate Graduating on time (bachelors) Graduating on time (masters)
Research	Citation rate Research publications (absolute numbers) Research publications (size-normalized) External research income Art related output Top cited publications Interdisciplinary publications Post-doc positions Strategic research partnerships Professional publications
Knowledge Transfer	Co-publications with industrial partners Income from private sources Patents awarded (absolute numbers) Patents awarded (size-normalized) Industry co-patents Spin-offs Publications cited in patents Income from continuous professional development Graduate companies College and university rankings
International Orientation	Citations per faculty
Internationalization of Faculty	Foreign language bachelor programs Foreign language master programs Student mobility International academic staff International joint publications International doctorate degrees
Regional Engagement	Bachelor graduates working in the region Master graduates working in the region Student internships in the region Regional joint publications Income from regional sources Strategic research partnerships in the region

The rankings and how they are used have received numerous criticisms that can be summarized into four types (Daraio et al., 2015): monodimensionality, lack of statistical robustness, dependence on the size of the DMU, and lack of consideration of the input–output structure. In addition to those who question the very concept of ranking.

Despite these criticisms, the influence of university rankings continues to increase, although it must also be recognized that, in general, both the information on the methodologies and the techniques used are improving.

Regarding the monodimensionality, the main criticism focuses on the fact that the most important or unique criterion is usually research, with very little influence of other criteria, for example, learning outcomes. Initiatives such as Assessment of Higher Education Learning Outcomes (ANHELO) have attempted to determine the possibility of comparable measurements of learning outcomes in higher education (Tremblay et al., 2012).The rankings can show a lack of statistical robustness, i.e., small changes in the data can produce considerable changes in the final order, and the removal or inclusion of a DMU can also produce unexpected rank reversals. Uncertainty and sensitivity analyses can be used to improve stability and to reduce the uncertainty of ranking systems (Dobrota et al., 2016).

There are many empirical approaches to solve problems that arise from the lack of consideration of DMU size and the input-output structure, such as parametric and nonparametric efficiency analysis techniques (Grosskopf et al., 2014).

With regard to the very concept of ranking, the main concern is that the results will be misinterpreted if they are disseminated through a simplistic analysis. Benchmarking initiatives, such as U-Multirank, attempt to provide meaningful information for the general public (Marope et al., 2013).

Benchmarking can be defined as a process facilitating systematic comparisons and evaluation of practices, processes, and outcomes conducted support improvement and self-regulation (Jackson, 2001). Benchmarking can be the appropriate tool to improve the HEIs by identifying best practices. According to the terminology of the European Network for Quality Assurance in Higher Education (ENQA), the real benchmarking is always improvement oriented. From this point of view, ranking of universities can be treated as an initial step in benchmarking (Kuzmicz, 2015).

6.3 Training HEI Managers on OR Methodologies

With increasing participation in higher education among young people, governments around the world are facing increasing pressure on their finances, inducing universities to operate with a higher degree of efficiency it is one of the causes of the growth of university evaluation systems throughout the world (Abbott & Doucouliagos, 2003). The creation of common spaces of higher education, such as the European Higher Education Area (EHEA), is also a reason to create mutual trust mechanisms in the correct functioning of HEIs.

Better management and planning in higher education require more information and research about university inputs and outputs and the relationship between them (Sinuany-Stern, 1991).

The objective of the chapter is to provide managers and leaders of HEI the knowledge that allows them to assess the possibilities and limitations of rankings and benchmarking techniques and how these techniques can be applied properly to the different levels of higher education systems.

The managers of HEIs need to have competencies in areas such as leadership, governance, accreditation, institutional research, international cooperation, finance, facilities, fundraising, human resources, student life, recruitment, and retention.

In many countries, it is not necessary to have specific qualifications to be members of the HEI director's board. One of the options for improving the competencies of directors of these institutions is executive masters designed for managers or executives with several years of work experience. These programs allow directors to further develop their skills while largely maintaining their day-to-day work schedule.

As in the MBA, the core subjects in these programs are analytical (accounting, economics, operations research, and quantitative analysis), functional (financial management, human resource management, and operations management), and ethics (social responsibility, corporate governance).

The design of all learner-oriented curriculum must be considered the heterogeneity of students, but this is a crucial aspect in disciplines such as MS/OR that deal with the application of advanced analytical methods to help make better decisions.

This chapter includes the themes of ranking and benchmarking that have been included in International Postgraduate Programs in Management of Higher Education Institutions in Colombia, Dominican Republic, Ecuador, and Spain, within the AUIP[1] network of universities, and Training Programs of the Institute of Statistics and Cartography of Andalusia.

In Sect. 6.3, we also describe the HEI benchmarking interactive tool (HEIBIT), a tool developed to facilitate the use of the techniques explained in these programs, which incorporates the methodology developed in five PhD theses of the doctoral program in Statistics and Operational Research at the University of Seville (Spain), (Alvarado, 2016), (Correa, 2016), (Fernández, 2015), (García, 2016) and (Morocho, 2015). The methodology has been applied at the national level in Ecuador for assets the accreditation and categorization process carried out by the Council for the Evaluation, Accreditation and Quality Assurance of Higher Education of Ecuador (CEAACES) in 2008 and 2013, at the regional level to assess the efficiency of research groups in Andalusia (Spain) (Pino-Mejías et al., 2010), and at school and institutional level in the Universidad Técnica Particular de Loja (UTPL. Ecuador).

The conceptual framework is based on the standards and guidelines for quality assurance in the European Higher Education Area (ESG), the standards of CEAACES, the National Agency for Quality Assessment and Accreditation of Spain (ANECA), and the National Accreditation Council of Colombia (CAN).

When the ranking and benchmarking processes are carried out by accreditation and quality assurance agencies, the results have relevant consequences in the HEI. There are many university systems in which the results of the evaluation process

[1]The Asociación Iberoamericana de Postgrado (AUIP) is an international nongovernmental organization recognized by UNESCO, dedicated to the promotion of postgraduate and doctoral studies. It is currently composed of almost 190 institutions of higher education in Spain, Portugal, Latin America and the Caribbean.

have a direct impact on the financing of institutions and may even involve the closure of programs and even the institution.

To provide users insight into the value and limits of any multicriteria analysis is necessary to consider, at least, the procedures used to select the variables, normalize its values, determine the weight of each variable, and the level of compensability allowed for the aggregation method (JRC, 2008). Another key aspect is the study of how the position of each institution in the ranking depends on the methodological options adopted. Sensitivity analysis and uncertainty analysis are useful tools to assess the robustness of rankings (Saisana et al., 2011).

When information about input and output of a process is available, Data Envelopment Analysis (DEA) is a well-established nonparametric methodology that is used to evaluate the efficiency of organizations, called DMUs, which employ optimization techniques (Ahn et al., 1988). The monitoring of the evolution of the HEI efficiency can be made using adaptations of the index of change in the productivity of Malmquist (Wolszczak-Derlacz, 2016).

6.4 Higher Education Institution Benchmarking Interactive Tool (HEIBIT)

The authors of this chapter have developed a learning tool, which can be accessed at http://semiestio5.us.es/shiny/HEIBIT/.

The tool is applicable to all levels of higher education: student, faculty, department, faculty, university, or national. It is designed to be used by the managers of the HEI so that they can know the possibilities and limitations of the techniques of OR / MS. The tool can be useful to close the gap between decision-makers and analysts but cannot replace the work of analysts who have the knowledge to apply the most appropriate technique in each circumstance.

When the ranking or benchmarking intends to build a unique measure to order the units to which it applies, the Handbook on Constructing Composite Indicators (JRC, 2008) provides a useful guide. The tool developed considers the methodological recommendations of this handbook.

HEIBIT has been developed in R (R Core Team, 2018), a freely available language and the environment under the terms of the Free Software Foundation's GNU General Public License, which provides a wide variety of statistical, graphical, and OR/MS techniques and runs on a wide variety of UNIX platforms, Windows, and MacOS.

HEIBIT is a web-based application that uses the framework of Shiny, an R package that makes it simple to build interactive web apps straight from R. You can host standalone apps on a webpage or embed them in R Markdown documents or build dashboards. You can also extend your Shiny apps with CSS themes, htmlwidgets, and JavaScript actions (Chang et al., 2018). Figure 6.1 shows the sidebar and flowchart of the application.

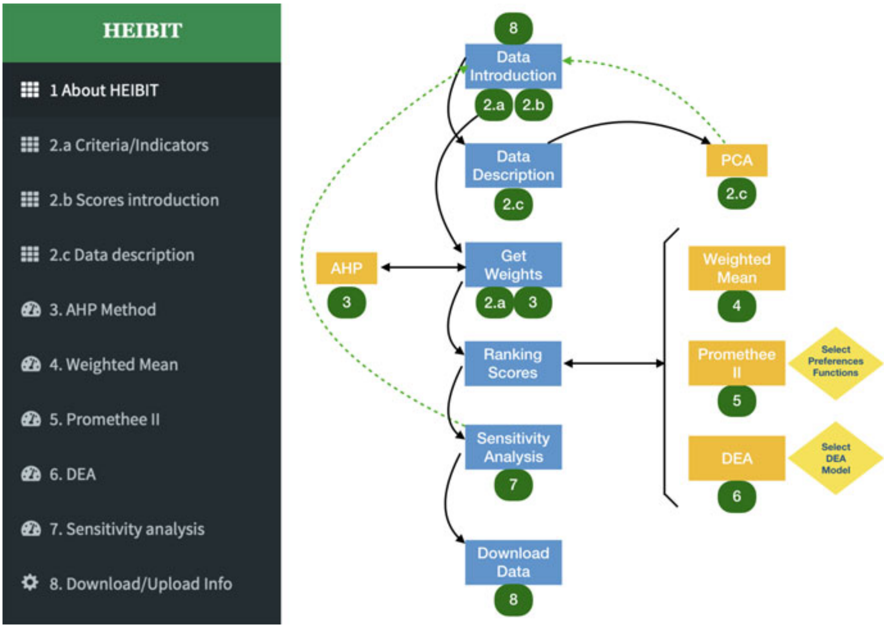

Fig. 6.1 HEIBIT sidebar and flowchart

6.4.1 Indicators Selection and PCA

From a qualitative point of view, the theoretical framework provides the basis for the selection of indicators. However, you also need quantitative tools to select the minimum set of indicators for each dimension you want to measure.

The dimensionality reduction techniques help to select a reduced set of indicators, capable of providing relevant information on each criterion. Principal components analysis (PCA) converts a set of indicators into a smaller number of uncorrelated components that account for most of the observed variance in the full set of indicators. The number of components and their correlations with the indicators help to select the indicators (Adler & Golany, 2002).

In Table 6.7, examples of application to HEI of PCA are shown.

To illustrate the operation of the application, a subset of only the first fifteen universities of ARWU (2018) has been used. Figure 6.2 shows the ARWU criteria, indicators, weights, and the input or output type of each indicator.

In Fig. 6.3, the values of the indicators in the HEIBIT app are shown.

The module 8 of HEIBIT allows the data to be downloaded or uploaded.

HEIBIT, using the factoextra package (Kassambara & Fabian, 2017), helps to easily perform the descriptive analysis of the values of the indicators, the calculation of the correlations, and the PCA; in Fig. 6.4, the correlations for the indicators of the example are shown.

Table 6.7 Examples of application to HEI of PCA

First Author (Year)	Country (HEI level)	DMUs (Number of DUMs)	Independent Variables (number)		Dependent Variables	Purpose of the analysis
Bobe and Kober (2018)	Australia (National)	Deans (56)	1. Age 2. Sex	3. Educational background 4. Tenure	1. Use of university management control systems 2. Financial performance measures 3. Non-financial performance measures	Management
Garcia-Aracil and Van der Velden (2008)	11 European countries (International)	Students (24.414)	Competences 1. Organizational (5) 2. Specialized (2) 3. Methodological (8)	4. Generic (5) 5. Participative (6) 6. Socio-emotional (7)	Natural logarithm of income	Quality assurance
Han and Finkelstein (2013)	Canada (University)	Students (5.459)	Questionnaire with items: 1. Having to respond to clicker questions and feedback improved my attention 2. The use of clicker feedback encouraged me to be attentive to classes 3. When using clicker feedback used in a class, I felt more involved 4. The use of clicker feedback improved my understanding of the course content	5. Clicker feedback helped me focus on what is should be learning in the course 6. I found using clicker feedback in the class worthwhile to my learning experience 7. Viewing the class answers and feedback to clicker questions helped me assess my understanding of the course content	–	Assessment

(continued)

Table 6.7 Continued

First Author (Year)	Country (HEI level)	DMUs (Number of DUMs)	Independent Variables (number)		Dependent Variables	Purpose of the analysis
Miller (2009)	Canada (Course)	Students (170)	Feedback embedded in a formative computer-based assessment 1. Directed to resource	2. Rephrased the question 3. Provided further information 4. Provided the correct answer	–	Assessment
Salas (2014)	Spain (National)	Students(3.209)	Modes of teaching and learning, and assessment: 1. Lectures 2. Group assignments 3. Participation in research projects 4. Facts and practical knowledge 5. Theories and paradigms 6. Teacher as the main source of information 7. Project and/or problem-based learning 8. Written assignments 9. Oral presentations by students 10. Multiple choice exams	Personal and educational characteristics: 11. Gender 12. Age 13. Father's education. 14. Secondary school grades 15. University degree 16. Duration of the degree. 17. Internships 18. Study abroad 19. Years of work experience since graduation	1.Ability to make your meaning clear to others 2-Ability to use time efficiently 3.Ability to work productively with others 4.Ability to perform well under pressure 5.Ability to rapidly acquire new knowledge 6.Ability to coordinate activities	Quality assurance
Tytherleigh et al. (2005)	UK (National)	HEI employee (3.808)	Occupational stress questionnaire 1. Perceptions of job (37) 2. Attitudes towards the organization (9)	3. Health (19) 4. Supplementary information (24)	–	Comparison

Vázquez Cueto (2008)	Spain (National)	Universities (47)	Efficiency of 21 DEA models. Inputs, combinations of: 1. Number of students 2. Number of professors and researchers	3. Number of seats in library Outputs, combinations of 4. Number of graduate students 5. Theses read	–	Efficiency
Webster (2001)	USA (National)	Universities (145)	1. Acceptance rate 2. Graduation rate 3. Alumni giving 4. Full-time faculty 5. Class size, 1–19 students 6. Class size, 50+ students	7. Predicted graduation rate 8. Average rating of quality 9. Freshman retention rate 10. SAT scores 11. %graduated in the top 10 percent of their high-school class	US News and World Report ranking of colleges and universities	Ranking
Wilkesmann and Lauer (2020)	Germany (National)	Faculty (3.406)	1. Teaching Motivation Intrinsic 2. Teaching Motivation Identified 3. Teaching Motivation Introjected 4. Teaching Motivation External 5. Gender 6. Discipline 7. Age	8. Perceived number of structural incentives 9. Perceived amount of didactic support 10. Vivid exchange on teaching matters with colleagues 11. Constructive feedback from students	Academic teaching	Quality assurance
Wilson et al. (1997)	Australia (National)	Universities (1.993)	Items of Course Experience Questionnaire (30)		–	Validation

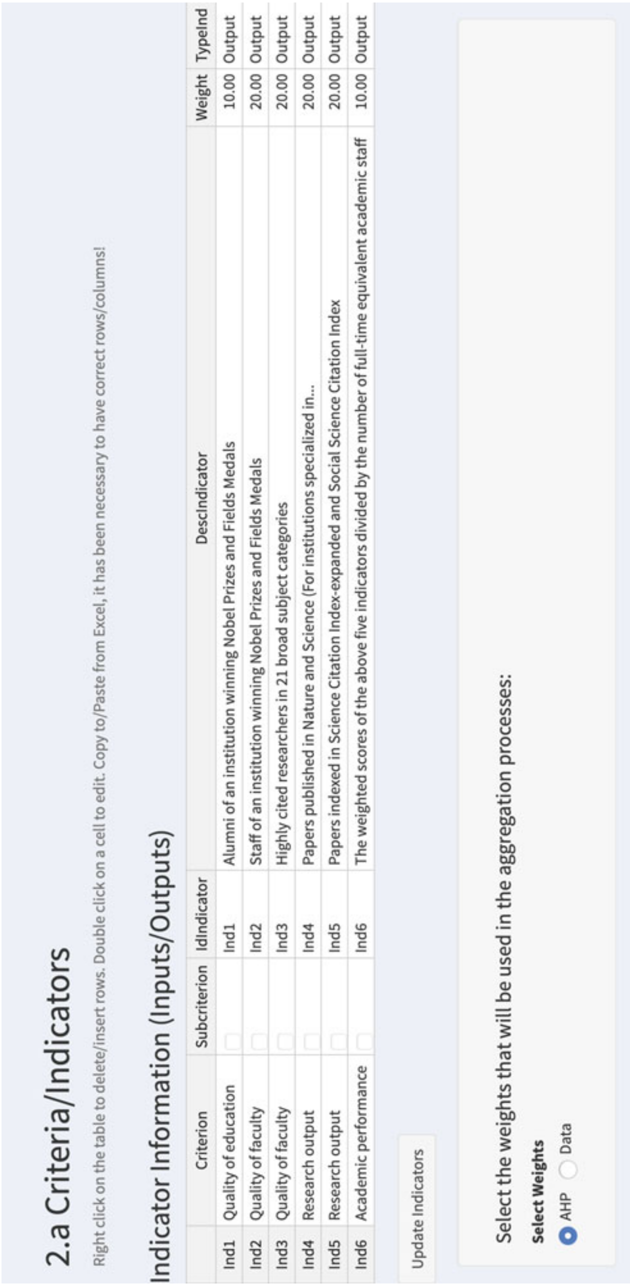

Fig. 6.2 Indicators description and weights

2.b Scores introduction

Right click on the table to delete/insert rows. Double click on a cell to edit. Copy to/Paste from Excel, it has been necessary to have correct rows/columns!

Indicators scores

It is assumed that the valuations are for Maximize.

	Institutions	Ind1	Ind2	Ind3	Ind4	Ind5	Ind6
1	Harvard University	100	100	100	100	100	79.6
2	Stanford University	44.5	88.5	76.6	78.6	76.5	56
3	University of Cambridge	82.3	95.4	56.7	57.6	70.9	59.5
4	Massachusetts Institute of Technology (MIT)	70.9	83.6	52.5	71.4	64.4	70.3
5	University of California. Berkeley	65.6	78.4	61.3	67.8	65.1	58.2
6	Princeton University	55.8	97.9	44.9	47.1	44.2	73.3
7	University of Oxford	50.8	54.2	61.3	52.6	77.1	46.8
8	Columbia University	62.8	67.2	41.8	56.4	71.5	33.7
9	California Institute of Technology	53.5	67.5	34.5	57.6	45	100
10	University of Chicago	59.2	90.1	35.8	42.5	52	44.2
11	University of California. Los Angeles	29.2	46.4	55.9	44.9	73.1	32.1
12	Cornell University	43.1	49.1	46.9	47.3	61.6	43.4
13	Yale University	47.1	49.7	44.9	53.4	58.7	35.7
14	University of Washington	24.9	37.4	54.2	49.1	75.9	31.4
15	University of California. San Diego	19	35.1	53.3	53	65.4	35.9

Fig. 6.3 Value of the indicators

The most correlated indicators for the fifteen universities are 3, 4, and 5 (highly cited researchers, papers published in Nature and Science, and papers indexed in SCI-expanded and SSC Index).

The indicators 1 and 2 (alumni and staff winning Nobel prizes and Fields Medals) also have a high correlation value.

PCA is useful to identify the relationship between indicators, components, and units. Figure 6.5 shows the projection of indicators and DMUs in the two-dimensional space generated by the first two components.

The biplot in Fig. 6.5 can be approximately interpreted as follows:

- A DMU that is on the same side of a given indicator has a high value for this indicator.
- A DMU that is on the opposite side of a given indicator has a low value for this indicator.

All the indicators are positively related to the first dimension, and Ind4, Ind3, and Ind5 are negatively related to the second component (Fig. 6.6).

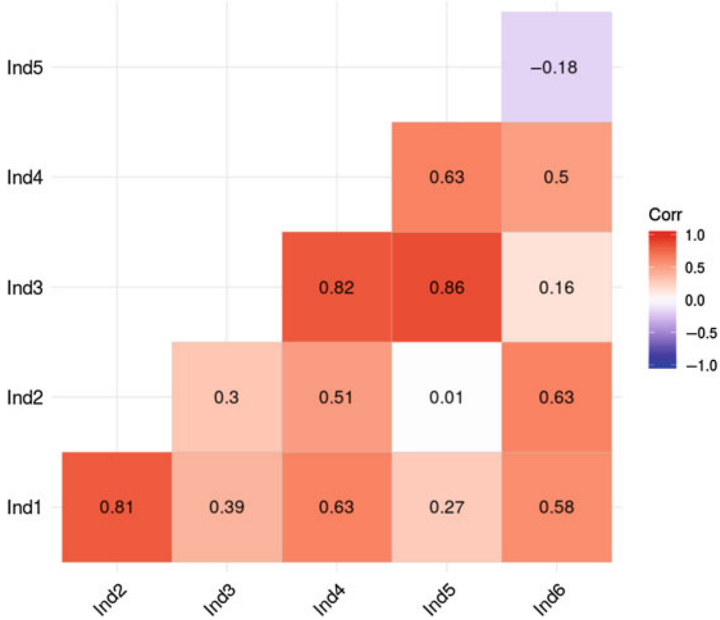

Fig. 6.4 Correlations between indicators

6.4.2 Weighting and AHP

In ARWU, THE, QS, and US News, the weights w_i of the indicators I_i have been set by the organizations that elaborate these rankings, and the global score is the weighted mean

$$\frac{\sum_{i=1}^{n} w_i \ I_i}{\sum_{i=1}^{n} w_i}$$

The weighting process is always conflicting, since the importance that each person or institution assigned to each criterion or indicator depends on many social, cultural, economic, or political factors. In the lower part of Fig. 6.2, the user can select weights that will be used to calculate the weighted mean, those in the "weight" column of the indicator information table in the same Fig. 6.2, or use the result of applying the Analytical Hierarchy Process (AHP).

The AHP is a measurement methodology through peer comparisons based on expert judgments. It was developed by Thomas L. Saaty in the 1970s (Saaty, 1980) and has been extensively studied and applied since then. An early application of AHP to HEI can be found in Saaty and Rogers (1976).

The principles of AHP can be applied in the weighting process as follows: if we have selected n criteria ($C_1, C_2, \ldots, C_n$), we assume that the decision-maker is

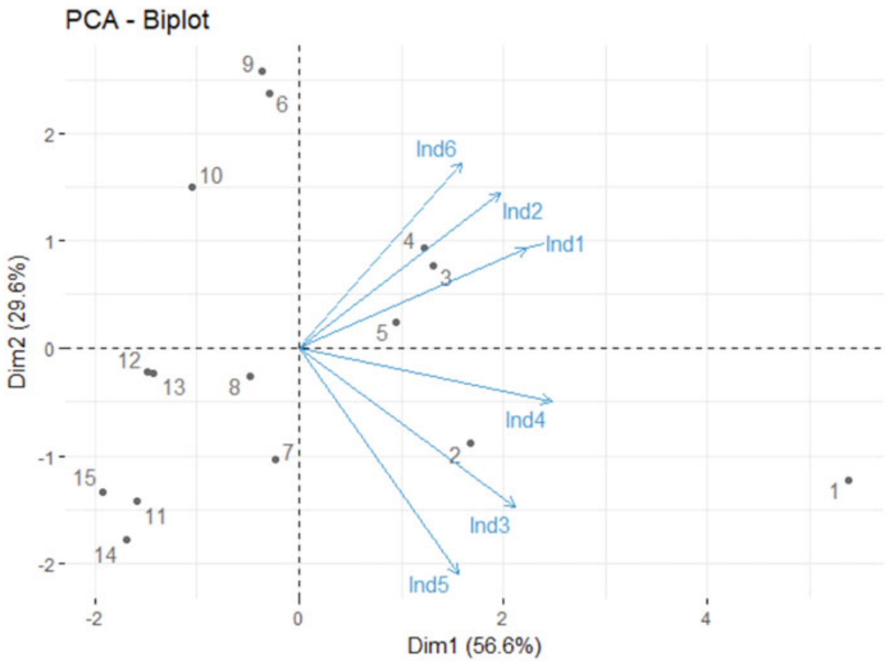

Fig. 6.5 PCA Biplot

Principal Component Analysis

	Component 1	Component 2
Ind1	0.8296781	0.3447636
Ind2	0.7349854	0.5366039
Ind3	0.7913614	−0.5521450
Ind4	0.9222324	−0.1848780
Ind5	0.5795348	−0.7848834
Ind6	0.5934568	0.6434757

Fig. 6.6 Correlations between components and indicators

capable of making a pairwise comparison between the different criteria. As a reason for this approach, Saaty wrote:

> In any comparison pair, the smaller of two elements A and B, say A, is taken as the unit and the larger one is estimated as a multiple of that unit. If we assume, as we always do, that we can derive weights, w_A and w_B for the elements on a ratio scale, then the absolute number assigned to the larger element is an estimate of this ratio and the comparison takes the form $\frac{w_A}{w_B}$. In the absence of a scale for measuring every element (which, due to the paucity of known scales, is nearly always the case) this approach is the most precise way to measure elements with respect to a property. (Saaty, 1994)

Table 6.8 Numerical rating in AHP

Verbal judgments of preferences between criterion *i* and criterion *j*	Numerical rating
C_i is equally important to C_j	1
C_i is slightly more important than C_j	3
C_i is strongly more important than C_j	5
C_i is very strongly more important than C_j	7
C_i is extremely more important than C_j	9
Intermediate values	2,4,6,8

The comparisons are made using a scale, which represents how much more one element dominates another with respect to a given attribute. In Table 6.8, we can see the numerical scales used in the AHP method.

Using the AHP scale, we construct a matrix *W*, with elements $w_{ij} = \frac{1}{w_{ji}}, \forall i$, j, being all the elements of W positives, by the Perron-Frobenius theorem, there is always a dominant eigenvalue $\lambda > 0$ such that its associated eigenvector has all its components greater than zero. Therefore, we can use as vector of weights $\{w_i, i = 1, \ldots, n\}$ the normalized eigenvector associated with λ. In general, $\lambda \geq n$, and $\lambda = n$ if *W* is consistent, i.e., when

$$w_{ij} = \frac{w_i}{w_j}, \forall i, \text{j}$$

Saaty defined the consistency index (*CI*) as:

$$CI = \frac{\lambda - n}{n - 1}$$

As a measure of consistency, the ratio *CR* is defined as the quotient between *CI* and an index obtained as the average of the *CI* values of a set of matrices with elements $a_{ij} = 1/a_{ji}$ generated randomly. A value of the consistency ratio $CR \leqslant 0.1$ is considered acceptable. Larger values of *CR* require the decision-maker to revise the scores.

If a criterion needs to be measured with more than one indicator, the same method can be used for the weighting of each indicator. If w_i is the weight of criterion C_i, and p_{ij} the weight of the indicator I_{ij} ($j = 1, \ldots, n_i$), with respect to the set of indicators of C_i, the global weight of I_{ij} will be $\psi_{ij} = w_i\, p_{ij}$, and $\sum_{i=1}^{n} \sum_{j=1}^{n_j} \psi_{ij} = 1$. We denote by N the total number of indicators, $N = \sum_{I=1}^{n} n_i$.

As an example of the use of AHP in Fig. 6.7, we can see the matrix of pairwise comparisons that produces the same weights as those established in ARWU.

In HEIBIT, AHP is used as a method for weighting the criteria. When some of the criteria are defined as outputs and others are defined as inputs, their indicators can be normalized as outputs before the aggregation step.

In Table 6.9, examples of application to HEI of the AHP are shown.

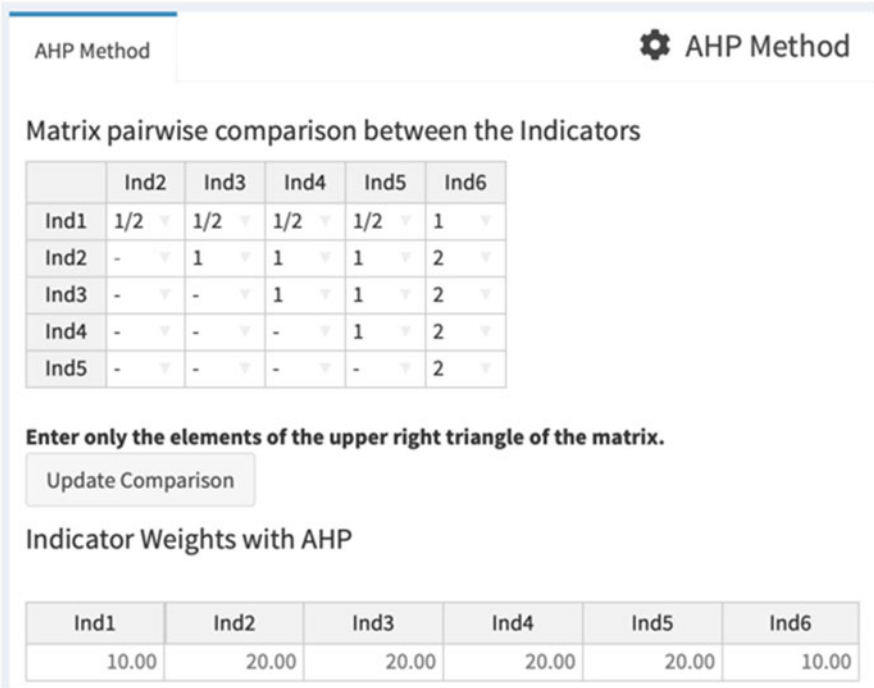

Fig. 6.7 AHP example

6.4.3 Normalization

The indicators are usually measured in different scales, so we need to select a normalization method. ARWU normalizes each indicator I_i with the transformation:

$$\frac{I_i - \min_i (I_i)}{\max_i (I_i) - \min_i (I_i)} * 100$$

Therefore, the rank for each indicator of ARWU is [0, 100].

In general, when the indicator is the measure of an input and the best DMU is, therefore, the one that has the minimum value for the indicator; the transformation is:

$$\frac{\max_i (I_i) - I_i}{\max_i (I_i) - \min_i (I_i)} * 100$$

In THE ranking, for example, the citation indicator is normalized to reflect variations in citation volume between different subject areas. U-Multirank applies

Table 6.9 Applications of AHP method to HEI

First Author (Year)	Country (HEI level)	Alternatives (Number of Alternatives)	Criteria (Number of indicators)		Purpose of the analysis
Begičević et al. (2007)	Croatia	E-learning implementation strategies (4)	1. Strategic readiness for e-learning implementation (3) 2. Basic ICT infrastructure for e-learning (4) 3. Human resources (6)	4. Legal and formal readiness for e-learning implementation (2) 5. Specific ICT infrastructure for e-learning (6)	Prioritization
Feng et al. (2004)	China (National)	Universities (26)	1. Full-time R&D personnel (8) 2. R&D expense (5) 3. Fruits of science and technology (10)	4. International communications (3) 5. Awards (3) 6.Income of technology transference (1)	Efficiency
Grandzol (2005)	USA (School)	Faculty (8)	1.Experience 1.1 Education (3) 1.2 Teaching Skills (3) 1.3 Business (3) 2. Scholarly Activities 2.1 Research Record (3) 2.3 Research Potential (3)	2.4 Collaboration (1) 3. Technological Skills 3.1 GP and Application Software (1) 3.2 Web and Online Course Delivery (1) 4. Flexibility in Teaching Capabilities (1) 5. Experience with Diverse Populations (1)	Selection
Lee (2010)	Taiwan (University)	Intellectual capital Indicators (7)	1. Administration (1) 2. Curriculum (1) 3. Technology transfer (1)	4. Research (1) 5. Teaching (1) 6. Service (1)	Assessing

Liberatore and Nydick (1997)	USA (University)	Research papers (15)	1. Objectives (1) 2. Justification (1) 3. Design (1)	4. Execution-Implementation (1) 5. Recommendations and implications (1)	Ranking
Rad et al. (2011)	Iran (National)	University majors (177)	1. Finance and Economics (1) 2. Society and Religion (1) 3. Industry (1) 4. Politics (1)	5. Services (1) 6. Agriculture (1) 7. Medicine (1) 8. Environments and natural sources (1)	Ranking
Saaty and Rogers (1976)	USA (National)	Scenarios (7)	1. Economic 1.1 Students (3) 1.2 Faculty (4) 1.3 Administration (2) 1.4 Government (6) 1.5 Private sector (4)	1.6 Industry 2. Political (with the same 6 sub-criteria and indicators) 3. Social (with the same 6 sub-criteria and indicators) 4. Technological (with the same 6 sub-criteria and indicators)	Planning
Tsinidou et al. (2010)	Greece (Universities)	University (1)	1. Academic staff (6) 2. Administration services (7) 3. Library services (4) 4. Curriculum structure (7)	5. Location (3) 6. Infrastructure (7) 7. Carrier prospects (5)	Evaluation
Turan et al. (2016)	Turkey (University)	Investment projects (5)	1. Teaching (4) 2. Research and Development (4)	3. Service and Social Responsibility (3) 4. Finance (1)	Selection
Wu et al. (2012)	Taiwan (Universities)	Universities (12)	1. Teaching Resources (6) 2. Internationalization (7) 3. Extension Education Service (4)	4. Discipline and Guidance (4) 5. General Education (3) 6. Administrative Support (4)	Ranking

different standardization procedures for quantitative indicators (e.g., number of publications or master's graduation rate) or qualitative (reputation surveys based on Likert scales), with the objective of classifying each university for each indicator in a group from the best group "A" to the lowest group "E." Given the great diversity of scales found in the review of the indicators used in university rankings, it is useful to employ a common framework that allows the normalization of any type of numerical indicator.

For an indicator I_i and two DMUs *u and v*, if $d= I_i\ (u) - I_i\ (v)$, we can choose a function $f_i(d)$ as a measure of the preference of decision-maker for *u* or *v*.

The preferences are always subjective; when we start the construction of a ranking, we cannot know a priori that each decision-maker prefers. Different managers of the same organization may have very different preferences (Cecconi et al., 2007). In the literature, we can find a wide variety of functions used to represent preferences. Among all of them, we have chosen the six types of functions that were initially used in the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) (Brans & Vincke, 1985). For these preference functions, a value of 0 means that there is no preference among the units being compared, while a value of 1 means an absolute, indisputable preference for one of the units.

- Type I—Usual preference function

$$P_I(d) = \begin{cases} 0 & d \leq 0 \\ 1 & d > 0 \end{cases}$$

Two units with positive differences generate a full preference for the better, even if the difference is very small.

- Type II—U-shape preference function

$$P_{II}(d) = \begin{cases} 0 & d \leq q \\ 1 & d > q \end{cases}$$

Two units with close values (difference $\leq q$) are indifferent. Two units with more different values (difference $> q$) generate a full preference.

- Type III—V-shape preference function

$$P_{III}(d) = \begin{cases} 0 & d \leq 0 \\ \frac{d}{p} & 0 \leq d \leq p \\ 1 & d > p \end{cases}$$

Two units with smaller different values (difference $\leq p$) generate a preference degree proportional to the difference.

- Type IV—Level preference function

$$P_{VI}(d) = \begin{cases} 0 & d \leq q \\ \frac{1}{2} & q \leq d \leq p \\ 1 & d > p \end{cases}$$

Two units with very close values (difference $\leq q$) are indifferent.

Two units with quite different values (difference > p) generate a full preference.

In between, two units with different values ($q <$ difference $\leq p$) generate a weak preference degree (preference degree = 1/2).

- Type V—Linear preference function

$$P_V(d) = \begin{cases} 0 & d \leq q \\ \frac{d-q}{p-q} & q \leq d \leq p \\ 1 & d > p \end{cases}$$

Two units with very close values (difference $\leq q$) are indifferent.

Two units with quite different values (difference > p) generate a full preference.

In between, two units with different values ($q <$ difference $< p$) generate a preference degree that is linearly increasing from 0 to 1 as the difference is increasing from q to p.

- Type VI—Gaussian preference function

$$P_{VI}(d) = \begin{cases} 0 & d \leq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}$$

The Gaussian preference function has been designed as an alternative to the linear (type V) preference function. It has a smoother shape without flat indifference and full preference areas. At the same time, it does not have any indifference or preference thresholds. Its shape is determined by another parameter: the s Gaussian threshold, which defines the position of the inflection point of the preference function curve.

Figure 6.8 shows examples of the six types of functions using as values of the parameters $q = 5$, $p = 10$, and $s = 3$.

6.4.4 Aggregation via PROMETHEE

The additive approach is the most used in the aggregation phase. Multiplicative aggregation has also been proposed (Leskinen & Kangas, 2005), (Tofallis, 2012), and the use of outranking techniques is also possible. HEIBIT uses PROMETHEE to obtain a global score.

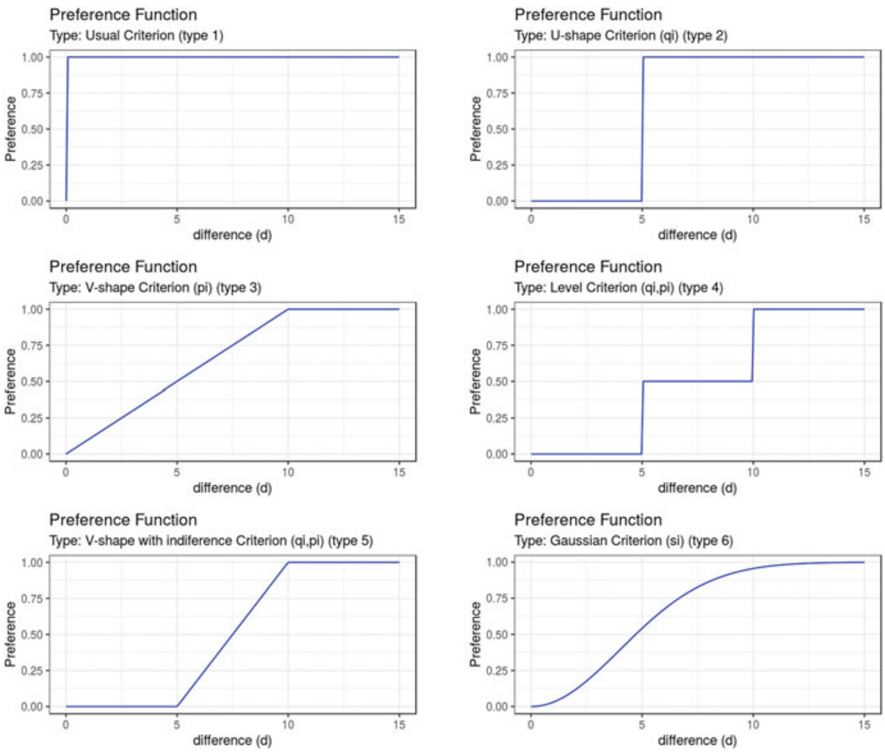

Fig. 6.8 Examples of preference functions

The first step in PROMETHEE consists of choosing, for each criterion, a preference function. This is used to compute, for each pair of alternatives u,v, a number between 0 and 1 representing a preference degree. In our application, we use the functions selected in the normalization phase to be associated with each indicator I_{ij}.

At the end of the first step, we, therefore, have a fuzzy preference relation for each indicator P_{ij} , which is the fuzzy relation associated with the indicator I_{ij}, and $P_{ij}(u, v)$ is the value of this relation for the pair *u, v*.

In the next step, these fuzzy relations are aggregated by means of a generalization of the Borda method (Marchant, 1996), obtaining a multicriteria preference index $\pi(u,v)$ of u over v, which takes all preferences into account with the expression

$$\pi\ (u, v) = \sum_{i=1}^{n} \sum_{j=1}^{n_j} w_{ij}\ P_{ij}\ (u, v)$$

The values $\pi(u,v)$ and $\pi(v,u)$ are computed for each pair of units, if U is the set of units to be evaluated, the positive flow

$$\phi^{+}(u) = \frac{1}{n-1} \sum_{v \in U, v \neq u} \pi\ (u, v)$$

represents what extent each alternative outranks all the others.

In the same mode, the negative flow

$$\phi^{-}(u) = \frac{1}{n-1} \sum_{u \in U, u \neq v} \pi\ (u, v)$$

represents to what extend each alternative is outranked by all the others.

In PROMETHEE II, the net flow $\phi(u) = \phi^{+}(u) - \phi^{-}(u)$ allows us to aggregate all the indicators considering the weights and to order the units.

The PROMETHEE methods can be used (De Keyser & Peeters, 1996) if the decision-maker is aware of the fact that the weights represent compensations and knows what can happen if one or more units are added or eliminated. We address this issue later when we address the limitations of multicriteria techniques and sensitivity analysis.

Table 6.10 shows examples of application to HEI of the PROMETHEE methods are shown.

In Fig. 6.9, the result of PROMETHEE II with the sample data and the usual preference criterion are shown.

6.4.5 Efficiency Analysis via DEA

HEIs are not classic firms whose aim is profit maximization; public HEIs, in particular, are by definition nonprofit organizations. Hence, we cannot assess their productivity by using the methods as cost-benefit analysis applied to the evaluation of companies producing goods or services and generating profit (Parteka & Wolszczak-Derlacz, 2013). The DEA has been used frequently to evaluate the efficiency of universities or their components (for example, degrees, research and training units, departments, laboratories, research centers). Berbegal and Solé (2012) performed an exhaustive review of the indicators used in DEA empirical studies in the first decade of the twenty-first century, classified by units of analysis, financial measures, human capital, infrastructures, teaching measures, research measures, knowledge transfer activities and overall measures (e.g., external rankings and internal surveys). Alvarado (2016) makes a review of the applications of this technique in universities and shows that the inputs considered most frequently are the number of professors and researchers, total funding and research expenses.

DEA was first introduced by Charnes, Cooper, and Rhodes (Charnes et al., 1978). It is a simple, yet powerful, method used to measure the relative efficiency of a group of homogenous firms or DMUs. A DMU can be defined as an entity responsible for converting input(s) into output(s) and whose performances are to be evaluated. The

Table 6.10 Examples of application to HEI of the PROMETHEE methods

First Author (Year)	Country (HEI level)	Alternatives (Number of Alternatives)	Criteria		Purpose of the analysis
Bedir et al. (2016)	Turkey (School)	Postgraduate Courses (6)	1. Content of the Course 2. Day of Course 3. Interests of Students	4. Instructor's Attitude 5. Academic Expectations	Selection
Chakraborty et al. (2017)	India (National)	States (28)	1. Number of primary schools per sq. km 2. Gross enrollment ratio (GER) in primary level 3. Student-teacher ratio in primary level 4. Average dropout rate in primary level 5. Number of secondary schools per sq. km. 6. GER in secondary level 7. Student-teacher ratio in secondary level	8. Average dropout rate in secondary level 9. Literacy rate 10. Number of colleges per sq. km. 11. GER in colleges	Benchmarking
Colson (2000)	Belgium (National)	OR Student's final work (8)	1. Applicability 1.1 its applicability to practice 1.2 its link with industrial applications 2. Contents 2.1 the consistency of the technical content	2.2. the scientific value and adequacy of the chosen OR methodology 3. General form 3.1. the quality of the style 3.2. the general quality and the cleverness of presentation	Ranking

First Author (Year)	Country (HEI level)	Alternatives (Number of Alternatives)	Criteria		Purpose of the analysis
Fadlina et al. (2017)	Indonesia (School)	Students (4)	1. Grade Point Average 2. Leave status	3. Status of Short repair/Short semester 4. Active Organizing	Ranking
Jati (2012)	Indonesia (School)	Teachers (3)	1. Publication 2. Research 3. Conferencing 4. Consultancy 5. Services	6. Teaching Attitude 7. Teaching Content 8. Teaching Method 9. Teaching Effect	Evaluation
Jati and Dominic (2017)	Indonesia (National)	University Websites (27)	1. Visibility. 2. Presence.	3. Openness. 4. Excellence.	Ranking
Özerol and Karasakal (2008)	USA (National)	Full-time MBA programs (9)	1. Alumni recommendation 2. Career progress 3. Faculty with doctorates (%) 4. FT Doctoral rank 5. FT Research rank	6. International faculty (%) 7. International mobility rank 8. International students (%) 9. Weighted salary	Ranking
Pekkaya (2015)	Turkey (School)	Career Alternatives (8)	1. Career opportunities 2. Job security 3. Job benefits and perks	4. Job flexibility 5. Personal issues 6. External influences	Ranking
Živković et al. (2017)	Serbia (University)	Strategic goals (6)	Results of evaluating the influence of 20 Strengths factors, 14 Weakness factors, 5 Opportunities factors	and 5 Threats factors on the realization of Strategic Goals, provided by 4 Decision-Makers	Planning

Promethee II

Ranking

Click on column title for ordering data.
The used weights are obtained from method AHP

	Ids.	Institutions	Net flow	Scores
1	UD01	Harvard University	13.8	100
2	UD02	Stanford University	7.6	69.31
3	UD03	University of Cambridge	6.4	63.37
4	UD05	University of California. Berkeley	4.6	54.46
5	UD04	Massachusetts Institute of Technology (MIT)	3.4	48.51
6	UD07	University of Oxford	2.4	43.56
7	UD08	Columbia University	-1.6	23.76
8	UD06	Princeton University	-2.6	18.81
9	UD09	California Institute of Technology	-2.8	17.82
10	UD14	University of Washington	-4.2	10.89
11	UD11	University of California. Los Angeles	-4.6	8.91
12	UD15	University of California. San Diego	-5.2	5.94
13	UD10	University of Chicago	-5.4	4.95
14	UD13	Yale University	-5.4	4.95
15	UD12	Cornell University	-6.4	0

Note: you must select the preferences functions associated with each indicator.

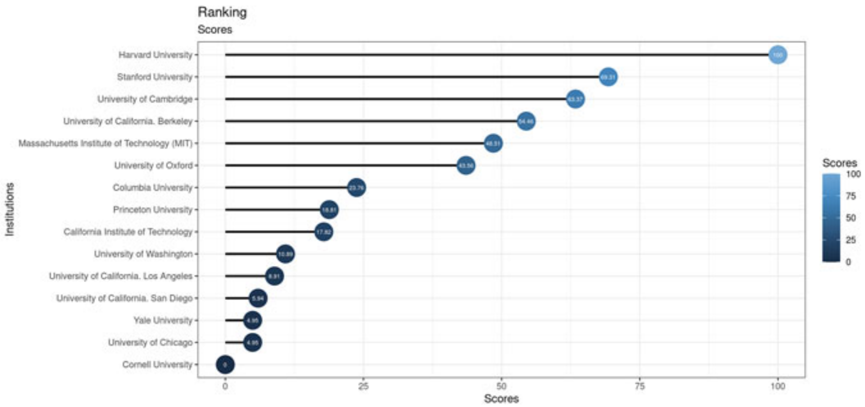

Fig. 6.9 PROMETHEE II example

popularity of DEA is due to its ability to measure relative efficiencies of multiple-input and multiple-output DMUs without prior weights on the inputs and outputs (Kuah & Wong, 2011).

In the efficiency analysis, you can choose an input orientation in regard to producing a fixed output minimizing the inputs or an output orientation when you want to maximize the outputs by fixing the inputs.

The most basic DEA model is known as the CCR model, which was named after the three authors. If we have m DMUs, with n_e inputs indicators X_e and n_s outputs indicators Y_s, $n_e + n_s = n$, each university (degree, etc.) γ can be considered as a DMU that uses the inputs $X_{\gamma 1}, \ldots, X_{\gamma n_e}$ and generates the outputs $Y_{\gamma 1}, \ldots, Y_{\gamma n_s}$, $\gamma = 1, \ldots, m$.

Assume the input weights $\varphi_{\gamma k}$ ($k = 1, \ldots, n_e$) and the output weights $\psi_{\gamma l}$ ($l = 1, \ldots, n_s$), we use the benefit of the doubt approach, so we want to obtain the best combination of these weights by solving the linear programming below, which is known as the multiplier form in DEA

$$\tau_1 \left(u_\gamma\right) = \max \sum_{l=1}^{n_s} \psi_{\gamma l}\, Y_{\gamma l}$$

$$s.t. \sum_{k=1}^{n_e} \varphi_{\gamma k} X_{\gamma k} = 1$$

$$\sum_{l=1}^{n_s} \psi_{\gamma l}\, Y_{\gamma l} - \sum_{k=1}^{n_e} \varphi_{\gamma k} X_{\gamma k} \leq 0$$

$$\varphi_{\gamma k}, \psi_{\gamma l} \geq \varepsilon, \text{for } \gamma = 1, 2, \ldots, n_e, k = 1, \ldots, n, and\, l = 1, \ldots, n_s.$$

We can fix $\varepsilon \geq 0$, as the smallest value allowed for the weights.

The model is run m times to identify the relative efficiency scores of all the DMUs. For each DMU, DEA selects a set of input weights φ_k^γ and output weights ψ_l^γ that maximize its efficiency score e^γ. The efficiency scores would fall between 0 and 1. Generally, we say that a DMU is efficient if it obtains the maximum score of 1; else, it is inefficient. For every inefficient DMU, DEA identifies a set of corresponding efficient DMUs that can be utilized as benchmarks for improvement.

If we need a unique set of weights, a cross-validation approach is to use as common weights the mean of the m weights obtained for each indicator.

$$\overline{\psi}_l = \frac{\sum_{\gamma=1}^{m} \psi_l^\gamma}{m} \quad l = 1, \ldots, n_s,$$

$$\overline{\varphi}_k = \frac{\sum_{\gamma=1}^{m} \varphi_k^\gamma}{m} \quad l = 1, \ldots, n_e$$

And use has a composite indicator for the DMU u_γ

$$\tau_2 \left(u_\gamma\right) = \frac{\sum_{l=1}^{n_s} \overline{\psi}_l\, Y_l^\gamma}{\sum_{k=1}^{n_e} \overline{\varphi}_k X_k^\gamma}$$

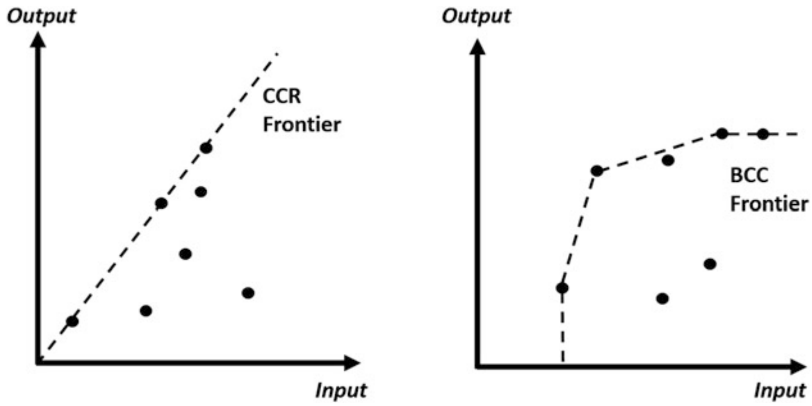

Fig. 6.10 CCR versus BCC production frontier

In the CCR model, a constant returns to scale (CRS) is assumed. A separation into technical and scale efficiencies is accomplished by the variable returns to scale (VRS) model developed by Banker et al. (1984). By way of illustration, when $n_e = 1$ and $n_s = 1$, Fig. 6.10 represents how the production frontier is calculated according to the BBC and CCR models.

When $n_e = 1$, the benefit of the doubt approach can also be used with all the indicators treated as outputs and a dummy input equal to one for all DMUs, and the CCR model is:

$$\max \sum_{l=1}^{n_s} \psi_{\gamma l} \; Y_{\gamma l}$$

$$\sum_{l=1}^{n_s} \psi_{\gamma l} \; Y_{\gamma l} \leq 1$$

$$\varphi_{\gamma k}, \psi_{\gamma l} \geq \varepsilon \geq 0$$

The production frontier with CCR and BCC models are convex, less restrictive assumptions are the free disposability of input or the free disposability of outputs. When we combine the two assumptions, we derive the assumption of the free disposability hull (FDH). An example of the application of DEA with FDH is the Aquameth benchmarking project, based on the collection and integration of a large dataset covering universities in the United Kingdom, Spain, Italy, Norway, Portugal, and Switzerland (Bogetoft & Otto, 2011).

The package Benchmarking (Bogetoft & Otto, 2015) can be used in interactive mode in HEIBIT. In Fig. 6.11, we can see that the DEA method applies the benefit of the doubt approach, finding the best possible weights for each unit; therefore, the

	Ids.	Institutions	Scores
1	UD01	Harvard University	1
2	UD09	California Institute of Technology	1
3	UD06	Princeton University	0.979
4	UD03	University of Cambridge	0.954
5	UD10	University of Chicago	0.901
6	UD02	Stanford University	0.885
7	UD04	Massachusetts Institute of Technology (MIT)	0.8624
8	UD05	University of California. Berkeley	0.784
9	UD07	University of Oxford	0.771
10	UD14	University of Washington	0.759
11	UD11	University of California. Los Angeles	0.731
12	UD08	Columbia University	0.715
13	UD15	University of California. San Diego	0.654
14	UD12	Cornell University	0.616
15	UD13	Yale University	0.587

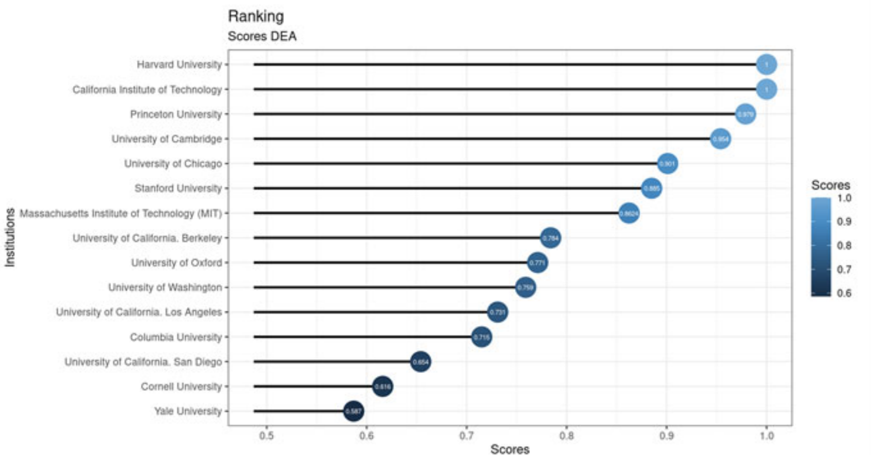

Fig. 6.11 DEA (VRS) scores of ARWU example with all indicators of type output

unit UD09 that has a 100 in the indicator IND6 (Fig. 6.3) reaches, together with the unit UD01, the maximum punctuation.

If we want to use the institution's endowment (in $ million) as input, we can add the new indicator and its values (Fig. 6.12).

With this input and one output obtained as the sum of the ARWU indicators, the production frontier is shown in Fig. 6.13.

Using the endowments as inputs and the six indicators of ARWU as output, the efficiency scores with the DEA (VRS) method are those shown in Fig. 6.14.

In this case, with the benefit of the doubt approach, only six institutions do not achieve maximum efficiency.

The DEA does not rank the DMUs that received a score of 1 (efficient DMUs), so that it is not possible to obtain a full ranking. A revision of techniques for ranking

Criterion	Subcriterion	IdIndicator	DescIndicator
Endowments		Input1	Endowments 2018

Harvard University	38303
Stanford University	26465
University of Cambridge	6965
Massachussetts Institute of Technology(MIT)	16529
University of California. Berkeley	4638
Princeton University	25917
University of Oxford	5432
Columbia University	10869
California Institute of Technology	2879
Institute of Chicago	7928
University of California, Los Angeles	2523
Cornell University	7230
Yale University	29351
University of Washington	2764
University of California. San Diego	1611

Fig. 6.12 Endowments 2018 (CAM, 2018; OX, 2018; TBS., 2018)

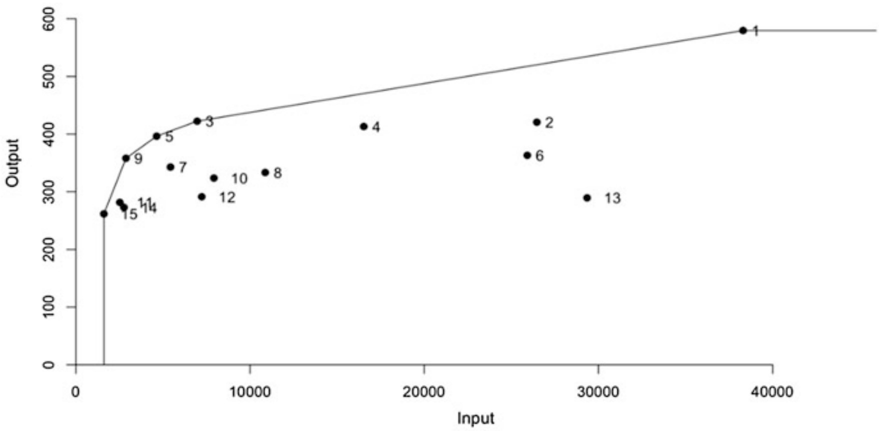

Fig. 6.13 Production frontier Endowment—Sum of ARWU indicators

in the DEA context can be found in Adler et al. (2002) and in Hadad and Hanani (2011).

In Table 6.11, examples of application to HEI of the DEA methods are shown; more applications can be found in Thanassoulis et al. (2016).

6.4.6 Dynamic Efficiency Analysis via Malmquist Index

If a DMU produces a vector of output Y_t using a vector of inputs X_t in time *t*, and we want to compare the efficiency in two times *t1* and *t2*, the Malmquist index can

Institutions	Scores
Harvard University	1.0000
Stanford University	0.9188
University of Cambridge	1.0000
Massachusetts Institute of Technology (MIT)	0.9539
University of California. Berkeley	1.0000
Princeton University	1.0000
University of Oxford	1.0000
Columbia University	0.9136
California Institute of Technology	1.0000
University of Chicago	0.9430
University of California. Los Angeles	1.0000
Cornell University	0.8132
Yale University	0.6249
University of Washington	1.0000
University of California. San Diego	1.0000

Fig. 6.14 Efficiency scores. Endowment—ARWU indicators

be used to assess the evolution of DMU efficiency using DEA (Färe & Grosskopf, 1996).

Let D_{t1} be the efficiency with respect to F_{t1}, and the frontier of production at *t1*. The change in efficiency with respect to F_{t1} is

$$\frac{D_{t1}\left(Y_{t2}, X_{t2}\right)}{D_{t1}\left(Y_{t1}, X_{t1}\right)}$$

and with respect to F_{t2}

$$\frac{D_{t2}\left(Y_{t2}, X_{t2}\right)}{D_{t2}\left(Y_{t1}, X_{t1}\right)}$$

the Malmquist index by definition is the geometric mean of the two changes in efficiency

$$M\left(Y_{t1}, X_{t1}, Y_{t2}, X_{t2}\right) = \left(\frac{D_{t1}\left(Y_{t2}, X_{t2}\right)}{D_{t1}\left(Y_{t1}, X_{t1}\right)} \frac{D_{t2}\left(Y_{t2}, X_{t2}\right)}{D_{t2}\left(Y_{t1}, X_{t1}\right)}\right)^{\frac{1}{2}}$$

An equivalent way to write this is

$$M\left(Y_{t1}, X_{t1}, Y_{t2}, X_{t2}\right) = \frac{D_{t2}\left(Y_{t2}, X_{t2}\right)}{D_{t1}\left(Y_{t1}, X_{t1}\right)} \left(\frac{D_{t1}\left(Y_{t2}, X_{t2}\right)}{D_{t2}\left(Y_{t2}, X_{t2}\right)} \frac{D_{t1}\left(Y_{t1}, X_{t1}\right)}{D_{t2}\left(Y_{t1}, X_{t1}\right)}\right)^{\frac{1}{2}}$$

Table 6.11 Applications of DEA methods to HEI

First Author (Year)	Country (HEI level)	DMUs (Number of DMUs)	Inputs		Outputs		Purpose of the analysis
Aoki et al. (2010)	Japan (National)	Universities (8 models) (31)	1. Number of faculties 2. Number of workers 3. Education and research expenses	4. Grant-in aid for management 5. General and administrative expenses 6. Profit from donations	1. Maximum deviations 2. Number of papers 3. Number of graduate students 4. Number of undergraduate Students	5. Number of books 6. Grant-in-aid for scientific research 7. Contract research funds 8. Profit from business.	Efficiency
Agasisti and Pérez-Esparrells (2010)	Italy Spain (Interna-tional)	Universities (57 Italian, 46 Spanish)	1. Number of students 2. Number of Ph.D. students 3. Number of professors (academic staff).	4. Financial resources available	1. Number of graduates 2. Amount of external resources attracted to research activities		Efficiency
Avkiran (2001)	Australia (National)	Universities (36)	1. Academic staff, FTE 2. Non-academic staff, FTE		Model 1 1. Undergraduate enrolments 2. Postgraduate enrolments 3. Research quantum (research component of Federal funds) Model 2 1. Student retention rate	2. Student progress rate 3. Graduate full-time employment rate Model 3 1. Overseas fee-paying enrolments 2. Non-overseas fee-paying enrolments	Efficiency
Beasley (1990)	UK (National)	Departments (52 Chemistry and 52 Physics)	1. General expenditure 2. Equipment expenditure 3. Research income		1. Undergraduates number 2. Postgraduates on taught course 3. Number of postgraduates who are doing research	4. Total number of postgraduates 5. Research rating: Star 6. Research rating: A+ 7. Research rating: A 8. Research rating: A-	Efficiency

Façanha et al. (1997)	Brazil (National)	Universities (52)	Tree factors obtained from 1. Area of buildings 2. Area of hospitals 3. Area of laboratories 4. Total number of students 5. Academic staff with doctoral degree 6. Academic staff with master degree 7. Academic staff with specialization degree 8. Academic staff with undergraduate degree	9. Academic staff of second and first-degree teaching 10. Administrative personnel at support level 11. Administrative personnel with high-school degree background 12.Administrative personnel with undergraduate degree or higher 13. Budget for current expenses 14. Incoming students at undergraduate level 15. Incoming medicaI residents	Tree factors obtained from 1. Number of undergraduate courses 2. Number of graduate courses—master degree level 3. Number of graduate courses—doctoral degree level 4. Certificates issued—undergraduate degree 5. Certificates issued—medical schools residence	6. Number of master degree thesis approved 7.Number of doctoral dissertations approved 8. Weighted average or MEC's evaluation: master degree courses 9. Weighted average of MEC's evaluation: doctoral degree courses	Efficiency
Ferrari and Laureti (2005)	Italy (University)	Graduates (2.236)	Average number: 1. . . . of full and associate professors per graduate 2. . . . of researchers per graduate 3. . . . of seats in lecture halls per student 4. . . . of lecture halls per student 5. . . . of books in the library per student	6. . . . of journals and reviews in the library per student 7. . . . of university pieces of furniture per student 8. . . . of university pieces of equipment 9. Final high-school mark	1. Average grade of the exams 2. Inverse of the length of study time		Efficiency

(continued)

Table 6.11 Continued

First Author (Year)	Country (HEI level)	DMUs (Number of DMUs)	Inputs		Outputs		Purpose of the analysis
Johnes and Li (2008)	China (National)	Universities (109)	1. Full-time staff to student ratio 2. % of the faculty with associate professor position or higher 3. Proportion of all students who are postgraduates	4. Research expenditure 5. Library books 6. Area of the buildings	1. Prestige of the HEI 2. Total number of research publications 3. Publications per member of academic staff		Efficiency
Köksal and Nalçaci (2006)	Turkey (School)	Departments (14)	1. Academic staff salaries 2. Potential of the department	3. Entering students	1. Research activities and quality 2.Education activities and quality	3. Other activities 4. Graduates	Efficiency
Pino-Mejías et al. (2010)	Spain (University)	Research groups (86)	1.Number of active doctors 2.Other research staff	3.Amount received in the call for grants to research groups	1.Income from public financing projects 2.Publications in ISI	3.Total thesis number 4.Total other projects 5.Total number of contracts	Efficiency
Sinuany-Stern et al. (1994)	Israel (University)	Departments (21)	1. Operational expenditures 2. Faculty salaries.		1. Grant money 2. Number of publications 3. Number of graduate students	4. Number of credit hours given by the department.	Efficiency
Torre et al. (2016)	Spain (National)	Universities (47)	1. Enrolled students in undergraduate and Master studies 2. Academic staff full-time equivalent	3. Students graduated in undergraduate and Master studies	1.Number of publications in the Web of Science-ISI	2. Number of national patents and patents with a Patent Cooperation Treaty international extension	Efficiency

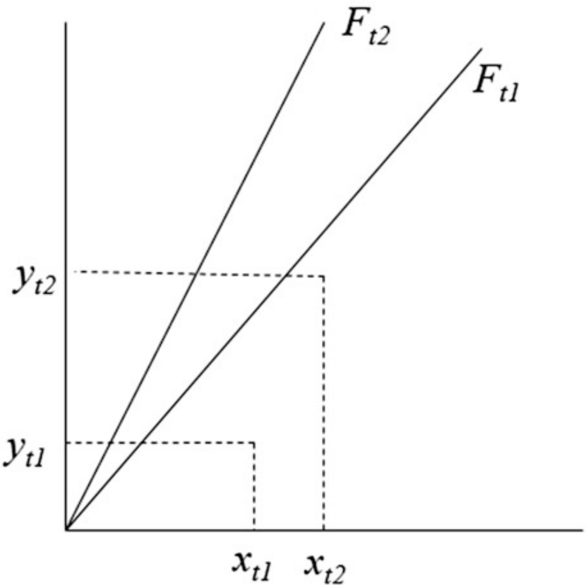

Fig. 6.15 Efficiency, technology, and productivity change

Worthington and Lee (2008), following Coelli et al. (2005), use Fig. 6.15 to illustrate the case of one input and one output with the constant returns of scale and orientation output.

If the frontiers of production are $F_{t1}(x) = \beta_{t1}\ x$ and $F_{t2}(x) = \beta_{t2}\ x$,the first term of the Malmquist index is the change in efficiency on the period (*t1*,*t2*):

$$\frac{D_{t2}\ (\ y_{t2},\ x_{t2})}{D_{t1}\ (\ y_{t1},\ x_{t1})} = \frac{\frac{y_{t2}/x_{t2}}{\beta_{t2}}}{\frac{y_{t1}/x_{t1}}{\beta_{t1}}}$$

And the second term is the frontier shift in this period.

$$\left(\frac{\frac{y_{t2}/x_{t2}}{\beta_{t1}}}{\frac{y_{t2}/x_{t2}}{\beta_{t2}}}\ \frac{\frac{y_{t1}/x_{t1}}{\beta_{t1}}}{\frac{y_{t1}/x_{t1}}{\beta_{t2}}}\right)^{\frac{1}{2}} = \frac{\beta_{t2}}{\beta_{t1}}$$

In Table 6.12, examples of application to HEI of the Malmquist index method are shown.

In general, the Malmquist productivity change index decomposes multiplicatively into an efficiency change component (EFFCH) and a technical change component (TECH). HEIBIT uses the package productivity (Dakpo et al., 2018) to obtain the Malmquist index and the two components

Table 6.12 Applications of the Malmquist index method to HEI

First Author (Year)	Country (HEI level)	DMUs (Number of DMUs)	Inputs		Outputs		Purpose of the analysis
Abbott and Doucouliagos (2001)	Australia (National)	Colleges of advanced education (25)	1. Number of academic staff 2. Number of general staff 3. Capital expenditures		1. Number of students		Productivity change
Agasisti and Dal Bianco (2009)	England Italy (International)	Universities (127 English, 58 Italian)	1. Number of students 2. Total amount of financial resources/incomes	3. The number of PhD students 4. Number of academic staff	1. Number of graduates	2. Total amount of external grants and contracts for research	Comparing
Agasisti and Pohl (2012)	Germany Italy (International)	Universities (69 German, 53 Italian)	1. Number of students 2. Number of professors	3. Expenditures	1. Number of university degrees awarded by students in the given year	2. Amount of money for research grants and contracts.	Comparing
Barra and Zotti (2016)	Italy (University)	Departments (28)	1. Equivalent personnel (professors +0:8*associate professors +0:6*researchers +0:4*assistant professors +0:2*non − academic staff)	2. Total amount of financial resources spends on research activities	Model 1 1. Number of publications (articles in international journals +0:75*articles in national journals+0:5*articles in international books +0:25*articles in national books) Model 2 2. External research funding obtained by the university Model 3 3. Productivity index	Model 4 4. Capacity of attracting resources index Model 5 5. Research productivity per cost of the academic staff index Model 6 Outputs 1 to 5.	Productivity change

Castano and Cabanda (2007)	Philippines (National)	Universities (30)	1. Number of faculty members 2. Property, plant, and equipment	3. Operating expenses	1. Student enrollment 2. Graduates per year	3. Total revenue	Performance evaluation
Førsund and Kalhagen (1999)	Norway (National)	Universities (100)	1. Number of academic staff (FTE) 2. Number of non-academic staff (FTE) full-time equivalents	3. Current expenses other than salaries 4. Building size in square meters	1. Final exams, short studies 2. Final exams, long studies	3. Research publications	Efficiency evolution
Hu et al. (2017)	China (National)	Universities (211)	1. Number of R&D staff with senior title 2. R&D grants		1. Number of monographs 2. Number of SSCI articles	3. Number of CSSCI articles	Comparison by university type and geographical area
Johnes (2008)	UK (National)	Universities (112)	1. Number of full-time academic staff plus 0.5 times the number of part-time academic staff 2. Expenditure on total administration and central services	3. Expenditure incurred on centralized academic services 4. Number of FTE first-degree and other undergraduates. 5. Number of FTE postgraduate students	1. Number of first-degree and other undergraduate qualifications awarded 2. Number of higher degree qualifications plus total other postgraduate qualifications awarded	3. Income received in funding council grants plus income received in research grants and contracts	Productivity change

(continued)

Table 6.12 Continued

First Author (Year)	Country (HEI level)	DMUs (Number of DMUs)	Inputs		Outputs		Purpose of the analysis
Parteka and Wolszczak-Derlacz (2013)	Austria, Finland, Germany, Italy, Poland, UK, and Switzerland (International)	Universities (266)	1. Number of students 2. Total academic staff	3. Total revenues	1. Number of publications 2. Number of graduates		Efficiency evolution
Thanassoulis et al. (2011)	UK (National)	Universities (121)	1.Total operating cost		1. Full-Time Equivalent undergraduate number (FTEUN) in medicine 2. FTEUN in sciences 3. FTEUN in non-sciences 4. FTE postgraduate number	5. Research funding 6."Third mission" or 'knowledge transfer" activity, measured by income from other services rendered	Cost Efficiency
Torre et al. (2017)	Spain (National)	Universities (47 public, 22 privates)	1. Enrolment 2. Academic staff FTE		1.Graduates 2. Publications (Web of Science)		Comparison public-private

In Figs. 6.3 and 6.12, we have the outputs and input used to illustrate the DEA application: the values of the ARWU indicators and the endowments in 2018. To obtain the Malmquist index, we need the data of another year. In Fig. 6.16, the values of the same input and outputs in 2017 are shown.

The values of the Malmquist index, efficiency change component, and technical change component for years 2017 and 2018 appear in Fig. 6.17. The last row contains the mean values.

The values of technical change lower that 1 are indications of negative "frontier shift;" only University of Chicago increased its total factor productivity since the growth of efficiency was enough to compensate the technical change.

6.4.7 Global Sensitivity Analysis

If we have two rankings produced by two sets of methodological decisions, to measure the dissimilarity between the two orders, we must use a procedure that obtains a 0 for the case in which the order does not change and reaches its maximum when the resulting order is the inverse of the original, that is, when the first unit passes to the last and the last to the first. If we denote $O_r(u_\gamma)$, the order of the DMU γ is in the ranking r; an example of this type of function is:

$$\overline{R} = \frac{1}{m} \sum_{\gamma=1}^{m} \left| O_1\left(u_\gamma\right) - O_2\left(u_\gamma\right) \right|,$$

where $|O_1(u_\gamma) - O_2(u_\gamma)|$ is the number of positions that change, up or down, unit γ from one ranking to another, m is the number of units, so $\overline{R}$ is the average number of changes. With this notation, the sensitivity analysis tries to identify the influence of methodological choices on $\overline{R}$; a multimodeling approach can be applied, exploring plausible combinations of the main methodological choices in the steps on constructing the ranking (Paruolo et al., 2013) and to employ global sensitivity methods, such as nonparametric, density-based, variance-based, moment independent and value of information-based sensitivity measures, (Sobol, 1993), (Borgonovo & Plischke, 2016).

For each m, the range of $\overline{R}$ is different, so we can denote $R^*(m)$ to the maximum of $\overline{R}$ for each m and use $\overline{R}_s = \frac{\overline{R}}{R^*(m)}$ as the normalized measure of the change in order.

In Table 6.13, the examples of application to HEI of uncertainty and sensitivity analysis methods are shown.

In HEIBIT, a graphical comparison of the ranking produced by the weighted mean (with the weights obtained from AHP), PROMETHEE II, and DEA methods is incorporated; Fig. 6.18 shows the graphical comparison of the classifications obtained by the three methods, using the labels of the DMUs of ARWU (2018).

For example, the values of dissimilarity index $\overline{R}_s$ are shown in Fig. 6.19.

Institutions	Time	Ind1	Ind2	Ind3	Ind4	Ind5	Ind6	Input
Harvard University	2017	100	100	100	100	100	79.6	36021
Stanford University	2017	44.5	88.5	76.6	78.6	76.5	56	24785
University of Cambridge	2017	82.3	95.4	56.7	57.6	70.9	59.5	4877
Massachusetts Institute of Technology (MIT)	2017	70.9	83.6	52.5	71.4	64.4	70.3	14968
University of California. Berkeley	2017	65.6	78.4	61.3	67.8	65.1	58.2	4638
Princeton University	2017	55.8	97.9	44.9	47.1	44.2	73.3	23812
University of Oxford	2017	50.8	54.2	61.3	52.6	77.1	46.8	5592
Columbia University	2017	62.8	67.2	41.8	56.4	71.5	33.7	9997
California Institute of Technology	2017	53.5	67.5	34.5	57.6	45	100	2607
University of Chicago	2017	59.2	90.1	35.8	42.5	52	44.2	7524
University of California. Los Angeles	2017	29.2	46.4	55.9	44.9	73.1	32.1	5001
Cornell University	2017	43.1	49.1	46.9	47.3	61.6	43.4	6757
Yale University	2017	47.1	49.7	44.9	53.4	58.7	35.7	27100
University of Washington	2017	24.9	37.4	54.2	49.1	75.9	31.4	2529
University of California. San Diego	2017	19	35.1	53.3	53	65.4	35.9	1611

Fig. 6.16 Input and outputs 2017

Institutions	Malmquist	EFFCH	TECH
Harvard University	0.94	1.036	0.908
Stanford University	0.932	1.07	0.871
University of Cambridge	0.938	0.987	0.95
Massachusetts Institute of Technology (MIT)	0.923	0.991	0.932
University of California, Berkeley	0.934	1.025	0.911
Princeton University	0.92	1.02	0.901
University of Oxford	0.79	0.868	0.911
Columbia University	0.923	0.985	0.937
California Institute of Technology	0.921	1	0.921
University of Chicago	1.002	1.093	0.917
University of California, Los Angeles	0.809	0.946	0.856
Cornell University	0.937	1.018	0.92
Yale University	0.917	0.989	0.927
University of Washington	0.995	1.163	0.856
University of California, San Diego	0.805	1	0.805
	0.912	1.013	0.902

Fig. 6.17 Malmquist index 2017 to 2018

The coefficient of correlation can be used as a measure of similarity of the different rankings. In Fig. 6.20, we can see how we have high correlations for low values of the dissimilarity index.

The Friedman test is a nonparametric statistical test similar to the parametric repeated measures ANOVA that can be useful as a measure of how close the various rankings are.

In Fig. 6.21 the result of the R-function Friedman test for the four rankings of the fifteen universities are shown.

This means that the Friedman test did not find statistically significant differences between the four rankings.

6.5 Main Drawbacks of OR/MS Techniques in Ranking and Benchmarking of HEI Education Institutions

In a ranking method, a rank reversal is a change in the order of the units when, for example, the set of units that are being ordered increases or decreases. The axiom of independence of irrelevant alternatives (IIA) says that “if unit *u* is preferred to *v* out of the choice set {*u*,*v*}, introducing a third option *x*, expanding the choice set to {*u*,*v*,*x*}, must not make *v* preferable to *u*.”

Table 6.13 Applications of uncertainty and sensitivity analysis methods to HEI

First Author (Year)	Country (HEI level)	DMUs (Number of DMUs)	Indicators		Purpose of the analysis
Dobrota and Dobrota (2016)	International (Universi-ties)	Universities (40)	Quacquarelli Symonds World University Ranking (QS) 2013 Indicators 1. Academic reputation 2. Employer reputation	3. Student-to-faculty ratio 4. Citations per faculty 5. International faculty ratio 6. International student ratio	Ranking
Dobrota and Dobrota (2016)	International (Universi-ties)l	Universities (20)	Academic Ranking of World Universities (ARWU) indicators	Alternative Ranking (ARWU Excluding Award Factor)	Robustness
Dobrota and Jeremic (2017)	International (Universi-ties)	Universities (field of Computer Science and Information Systems in QS Information and Computing Sciences in URAP) (15 Top-ranked and 8 Indian universities)	QS indicators University Ranking by Academic Performance (URAP) indicators: 1. Article	2. Article Impact Total 3. Citation Impact Total 4. International Collaboration	Robustness
Gnaldi and Ranalli (2016)	Italy (National)	Universities (56)	1. For each study program, average number of permanent teachers belonging to the basic subject areas which qualify the educational profiles offered by the programs 2. Ratio between the number of enrolled students to the second academic year who acquired at least 2/3 of the available credits and the total number of matriculated students 3. Ratio between the number of credits acquired by enrolled students and the total number of available credits 4. Ratio between the number of study program which collected data on "Students' opinions on study programs" and the total number of study programs in the same academic year	5 Percentage of graduated students who were employed 3 years after graduation 6. Composite Indicator of Research quality 7. Economic Valorization of Research Products Index 8. Ratio between number of permanent teachers taking part in "Projects of National Relevant Interest" and the total number of permanent teachers. 9. Indicator of European funds and projects obtained for research	Robustness

Lin et al. (2013)	International (Universities)	Universities (field of Physics) (299)	Indicators of Higher Education Evaluation and Accreditation Council of Taiwan University Ranking (2011 HEEACT) with four counting methods of 1988–2008 physics papers records indexed in ISI WoS. 1. Whole counting	2. Straight counting using first author 3. Straight counting using corresponding author 4. Fractional counting	Robustness
Maričić et al. (2017)	International (Universities)	Universities (500)	ARWU indicators and Alternative Ranking (ARWU Excluding Award Factor)		Robustness
Paruolo et al. (2013)	International (Universities)	Universities (500)	ARWU and THES indicators		Robustness
Saisana et al. (2011)	International (Universities)	Universities (50)	ARWU and THES indicators		Robustness
Shehatta and Mahmood (2016)	International (Universities)	Universities (100)	ARWU, QS, THES, US News and World Report Best Global University Rankings (USNWR), National Taiwan University Ranking (NTU), and URAP		Comparing
Waheed et al. (2011)	Canada (Universities)	Universities (11)	Driving forces (7 indicators) Pressure (15 ind.) State (15 ind.)	Exposure (12 ind.) Effects (7 ind.)	Assessment
Zornić et al. (2016)	International (Universities)	Universities (field of Education) (15)	QS indicators and University Ranking by Academic Performance (URAP) indicators		Comparing

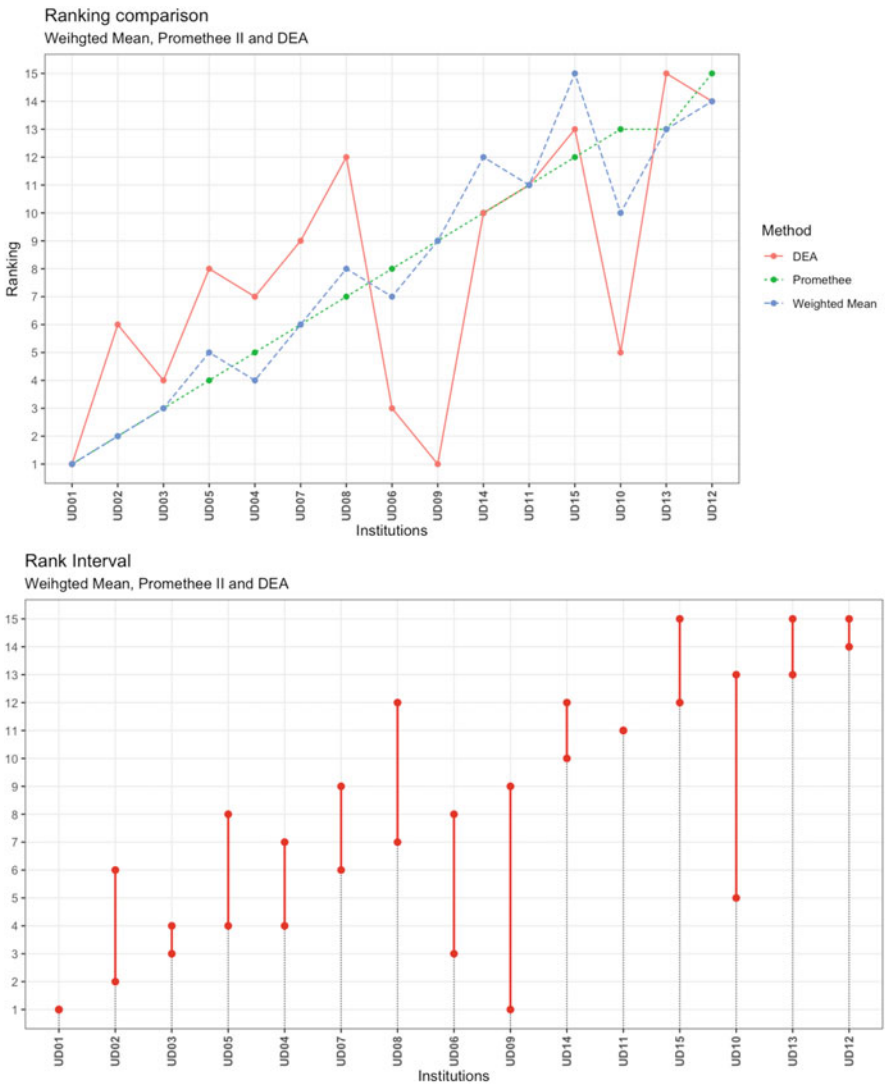

Fig. 6.18 Sensitivity analysis example

The Arrow theorem (Arrow, 1963) was developed for voting systems and can be used for our problem as follows. If the number of indicators is finite and there are at least three units, no aggregation method can simultaneously satisfy universality, transitivity, unanimity, IIA, and nondictatorship.

Violations of IIA are particularly troubling in our context where many DMUs are considered simultaneously; good information is available about each alternative's ranking with respect to each indicator being aggregated (Patty & Penn, 2018).

	OrderPromethee	OrderDEA	OrderWeighted
OrderIni	0.18	0.38	0.05
OrderPromethee		0.39	0.12
OrderDEA			0.37

Fig. 6.19 Values of dissimilarity index

	OrderPromethee	OrderDEA	OrderWeighted
OrderIni	0.91	0.68	0.98
OrderPromethee		0.59	0.95
OrderDEA			0.69

Fig. 6.20 Correlation coefficients

Friedman Test for rankings:

```
        Friedman rank sum test

data:  as.matrix(df)
Friedman chi-squared = 1.6132, df = 3, p-value = 0.6564
```

Fig. 6.21 Friedman test

The majority of currently published university rankings combine various measures to produce an overall score using an additive approach, and the choice of normalization affects the order in which universities are ranked. The multiplicative aggregation overcomes these difficulties (Leskinen & Kangas, 2005) but has the shortcoming of assigning a 0 global score to the DMUs with some indicator with a score 0.

As we have seen in the previous section, all the methodological choices for constructing a university ranking influence the final order of DMUs; HEIBIT helps the decision-maker to measure the influence's degree of each choice and illustrate the possibilities and limitations of rankings and benchmarking techniques, and how these techniques can be applied to the different levels of higher education systems.

6.6 Conclusions and Future Development

The review that was made of the application in the HEIs of the techniques analyzed in this chapter shows the great potential of these techniques, although it also shows that they are still less used in HEIs than in other sectors such as, for example, business management. One of the possible reasons for the lack of exploitation of the OR / MS techniques on colleges and universities is the heterogeneity in their managers' initial training. Therefore, the offer of training programs specifically designed for university managers, such as the postgraduate programs for which HEIBIT has been developed, can increase the use of OR / MS techniques and have a positive impact on improving efficiency and the effectiveness of HEIs.

Given the importance of international and national rankings on the reputation of HEIs, the use of some of the best-known rankings to illustrate the use of decision-making techniques favors learning their possibilities and limitations.

Tools to aid learning, such as HEIBIT, are useful to enable the application of advanced quantitative methods to broader groups of managers, helping them identify the correct experts to find the best alternatives for multicriteria problems that arise in their institutions.

With respect to the future developments of HEIBIT, we are working on a module that helps the decision-maker to choose the methodology, or the combination of several methodologies, suitable for frequent problems in the management of HEIs.

The second line of work is to incorporate other applicable techniques in HEIBIT to construct rankings that have shown to be more promising in the carried out review, as an example the techniques for obtaining full rankings in the DEA context.

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Chapter 7
Balanced Scorecard in Strategic Planning of Higher Education: Review

Zilla Sinuany-Stern and H. David Sherman

Abstract This chapter provides a review of the Balanced Scorecard (BSC) applied to higher education institutions (HEIs). BSC was developed in the 1990s as a comprehensive method to measure and manage organizational performance. BSC translates an organization's mission statement and strategy into specific, measurable goals and monitors the organization's performance in regard to achieving these goals. We review publications reporting application of BSC to higher education institutions over 25 years reported by the organizational level, country of application, and use of other methodologies combined with BSC. The large number of applications in many different ways suggests continued future potential for additional applications of BSC in higher education, such as quality assurance.

Keywords Higher education · Balanced scorecard · Strategic planning · Quality assurance · Performance measurement · Performance management

7.1 Introduction

One of the management tools used in business that academics and managers have used successfully in Higher Education (HE) is the Balanced Scorecard (BSC) see: Hafner (1998), Chen et al. (2006), Beard (2009), Taylor and Baines (2012), Lassoued (2018), and others. This chapter reviews the literature of BSC in HE over the last 25 years. In this introduction, we offer some perspective on BSC as applied to business, not-for-profit organizations, and HE. We also describe the motivation

Z. Sinuany-Stern (✉)
Department of Industrial Engineering & Management, Ben Gurion University of the Negev, Beer-Sheva, Israel
e-mail: zilla@bgu.ac.il

H. D. Sherman
DMSB—Northeastern University, Boston, MA, USA
e-mail: h.sherman@norhteastern.edu

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for using the BSC to manage HE organizations and the reasons BSC continues to be a valuable tool in HE for current and future use.

BSC was developed in the 1990s by Robert Kaplan and David Norton (1992) following their study of large businesses to identify ways to assess and manage corporate performance. BSC evolved into a respected and widely used approach to strategic planning, which ideally 1. translates an organization's mission statement and business strategy into specific groups of goals, 2. develops and defines corresponding measures for each of the goals, 3. measures and monitors the organization's performance in regards to achieving each of the goals, and 4. uses the information about where individual goals are and are not achieved to initiate management actions to help the organization meet their goals in future periods. The BSC has proven valuable to many organizations, including businesses in a wide variety of industries, government, and not-for-profit institutions. The way BSC is adapted, and the way it is used in practice varies, as it is adapted to the organization's characteristics and management objectives. In business enterprises that are listed on public stock exchanges, the owners of the business are the shareholders, and a key and always present priority is financial performance, as this is the basis for providing returns to investors by generating cash to, for example, pay dividends, or increasing earnings to raise the value of the business common stock. The BSC applied to business can be described as a set of performance measures/criteria that include but also support the financial measures. Initially, the value of the BSC was to provide a holistic view of the business/organization via *performance measures* that go beyond financial performance measures and compensate for limitations in financial performance measures. Financial measures reflect the business performance in prior periods, so for example, the income statement is income earned last month, last quarter, or last year. Net income is one of the key financial measures, but it does not address the more important question of how much might be earned in future periods—next month, next quarter, next year, or future years? Financial statements are described as lagging indicators, as they report on the past. BSC attempts to incorporate leading indicators that are mostly nonfinancial that suggest future performance potential. While this will be more clear in the following discussion, examples of these lead indicators might be number of patents on new drugs suggesting new products that will be sold in future periods and the development of new customers that will be the source of future sales. While no measure can predict the future, the idea is that a business that is developing patents that are focused on creating new products or more competitive products will generate future products that will generate future sales and increased future income. The nature and quality of the patents are not reflected in the number of new patents, which suggests the need for yet other measures to evaluate the patents and an evaluation of the potential of the patents may be yet another measure included in the BSC as a leading indicator. The point is that these leading indicators need to be explicitly included to focus the organization on achieving future goals. The expectation is that by achieving the target level of these leading indicators in the BSC, management will be more likely to achieve its overall future goals and strategic objectives.

Before describing the basic BSC structure in corporations, we offer a preview of the value to not-for-profit organizations and to HE, as the value is substantial for reasons that differ from corporate use. Not-for-profit organizations do not have a primary objective to generate added profits or, as it is said, "maximize shareholder wealth." They are not owned by shareholders, and indeed, they generally do not have owners but are governed by a board of directors or trustees or by a government organization. Financial measures generally are not the key measure of their performance. The objective of a not-for-profit might be described as providing as much service in their mission as possible at the lowest cost. The financial performance might be considered secondary to providing their services. Instead of profit maximization, the financial objectives might be minimizing cost along with fund raising and maintaining cash flow to sustain the organization. Not-for-profit use of BSC is found in museums, health care organizations, government organizations, and HE. BSC is, in these cases, adapted to the organization goals and mission. While careful financial management in a not-for-profit is critical helping to sustain and increase their services, a museum or hospital, or college would not be considered to have excellent performance just because they generated a profit. The volume, range, and quality of their services would likely be the primary measures of their success.

Quality is a dimension that is present in the corporate organization as well as the HE and needs to be incorporated in the BSC. Quality is a leading indicator in that it suggests whether the product will meet customer expectations and generate repeat sales in the future. In education, quality can include meeting the student expectation and meeting employer expectations about the capabilities of the graduates of the education program. High quality can generate continued demand for education. The quality of new patents in a business will impact the success of future products. The quality of the faculty will impact the reputation of the educational institution and can impact the ranking and the number of students that apply for the HE educations programs in the future.

There is also a relationship between financial measures and other leading indicators in corporate and HE applications. An organization can boost current period financial results by reducing current operating expenses. A business can reduce current investment in patents which would decrease current period expenses and increase current period net income. This may result in weaker future sales and income due to lack of competitive new products. Similarly, Higher Education Institution (HEI) can reduce the hiring of new faculty or defer investment in updating existing education programs resulting in lower operating expenses in the current period, which would generate stronger financial results in the form of higher surplus or reduced deficit and more cash. However, this could result in a lower ranking for the education institution where ranking includes a measure of the faculty quality and the competitiveness of the HE programs, which can reduce the number of future new student applications. In short, the BSC seeks to incorporate leading indicators that capture the more important elements that management needs to successfully manage to achieve strong future performance consistent with the organization's mission and strategic goals.

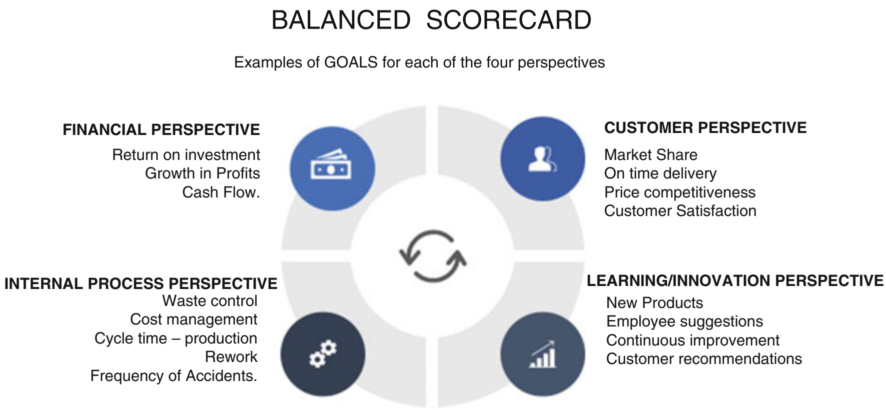

Fig. 7.1 Corporate balanced scorecard illustration (format adapter from Lorin Ipsun BSC presentation, free internet templates—https://powerpointify.com/balanced-scorecard-free-powerpoint-template)

The general structure of BSC is to develop strategic goals along four perspectives as shown in Fig. 7.1:

1. Financial perspective—are we meeting the expectations of our Shareholder?
2. Customer perspective—are we satisfying our customers?
3. Internal processes—are we doing the right things (effectiveness)? And doing things right (efficiency)?
4. Learning and Innovation—are we prepared for the future?

The process of identifying the goals in each of the four perspectives requires cooperation of individuals associated with that perspective in the business, including senior managers, functional experts like human resources and information systems, and others that can help understand ways each perspective contributes to the strategic goals of the organization. This can require substantial personnel time and effort and generally requires the strong support of senior management. The costly personnel time and effort to explain and install the BSC is one of the barriers to adapting BSC. The need for senior management support is an element that is required for BSC to be effective, and without this support, it may be of marginal value. Beyond the time and other costs of adapting the BSC, there are no reports that we are aware of where it was viewed as damaging in any way to the organization.

Ultimately management identifies the goals that need to be achieved to reflect the organization's strategy and achieve its mission; for each goal, a way to measure that goal is designated, and for each measure, a target that is considered good progress to meeting the goal is designated. These measures may be quantitative or qualitative (e.g., have we increased market share can be a qualitative measure and may be considered sufficient instead of an actual market share quantitative goal). Incorporation of qualitative goals offers another attractive advantage to not-for-profit and HE use of the BSC. The BSC is then placed into use, and the actual results are measured for each goal compared to the target.

The BSC for the business as a single entity will often be different from the goals and measures of the department and other parts of the organization. Balanced scorecard has been developed to the level of the individual manager, and performance against goals in individual scorecards have been used as a primary basis for evaluating and rewarding individual manager performance.

An example of the value of BSC to a business is the translation of strategy into the way the organization focuses on meeting the goals and the way the measures in the individual manager scorecards help the organization achieve strategic goals. Organization strategy may be described in grand terms with broad and sometimes technical goals. The individual manager goals in the BSC have been described as helping to "make the mission real" and as motivating the individual manager to accomplish particular goals, which contributes to achieving the corporate mission. For example, improving the relationship with customers can enhance the sales and even the speed of collecting bills. Speeding up collections increases several financial goals, such sales, profits, and cash flow. The salesperson's BSC might include measures of ways they improve customer relations, such as time spent with the customer. By meeting this customer goal, the salesperson is indirectly helping to meet financial goals as well as improving the likelihood of future sales.

Another example is that poor internal processes can lead to delays in customer shipments, defects, customer dissatisfaction, reduced sales, and reduced profits. The industrial engineer that has measures such as reducing cycle time and reducing stockouts is meeting the internal process goals, which improves customer satisfaction and can lead to increase sales and increased profitability. The industrial engineer with cycle time and stockouts in their scorecard is helping achieve the overall mission and improve financial performance without the need to explicitly know or understand the corporate mission and strategic goals. The four perspectives in the BSC are interrelated, and the success or failure to meet one set of goals in one part of the scorecard can enhance success or failure to meet goals in other areas.

Parallel interrelationships are found in HE. For example, in a HE environment, the institution may have objectives of raising their ranking among external rating organizations as a means of attracting more students to apply to their institution. Raising ranking in some cases is based on the percent that completes all 4 years in college (a student retention goal) and the percentage of students that are employed after graduation. The dean of the school may have little direct influence over student employment but may have a retention goal in the dean's scorecard. The employment placement manager may have little influence over retention but can directly impact the placement of graduates. For the placement manager, the placement percentage could be the goal included in the placement scorecard. The result in each part of the organization would ideally be motivated to reach its individual BSC goals, which would ultimately help the HE organization achieve its goal of raising the ranking. The dean meeting retention goals and the placement manager meeting student placement goals are each contributing to improving the HE ranking without their need to know how to improve the ranking. This is an example of how HE

BSC can “make the mission real.” The dean and the placement manager may well understand that the mission is to have a high ranking to build the reputation of the HEI, but they may not know how they can or if they can help in that mission. The BSC directly provides a way for them to contribute toward achieving the mission goal of improving the ranking and achieving the organization’s strategic goals.

Before focusing on HE, consider some of the typical goals included in the basic four perspectives for a corporate entity. A for-profit education organization might have similar elements as any corporation. As noted earlier, the not-for-profit is not likely to have financial as the top goal. The financial elements were presented as top perspective as in Fig. 7.1, and while the perspective may be displayed in the same form, a not-for-profit might have the customer (students) as the top perspective and financial as one of the other perspectives.

Figure 7.1 is an example of a corporate BSC and the types of goals that might be included. Each organization would develop its own goals based on its strategic objectives, so that two competing organizations may well have very different scorecards. For each of the goals, a specific way of measuring the progress to the goal that is considered appropriate, by the group developing the scorecard, is selected. A target for that goal would be set as the goal over some period of time. For example, in the internal process goal of rework, the measure that might be used is the number of second quality or defective units requiring rework as a percentage of total production. The target might be that no more than 5% are seconds requiring rework. During the measurement period, such as a quarter of the year, the defects would be measured, and if the percentage were above 5%, that would be flagged as a weakness requiring some remedial actions by management. Each of the performance measures on the scorecard would be tracked as in this example, and that would be applied to each level of scorecards. For example, a business might have four goals in each perspective, each with a designated way to measure progress to that goal, a measure of how well the organization did in achieving each of the 16 goals would be reviewed on a regular basis and used to evaluate progress toward achieving strategic goals and implications where individual goals are not achieved.

Section 7.2 presents the adaptation of BSC to HEIs, Sect. 7.3 presents and analyzes the literature on BSC in HE, and Sect. 7.4 concludes.

7.2 BSC Adapted to HE

BSC provides an integrated perspective on goals, targets, and measures of progress expressed by tangible measured objectives, which represent the balance between the shareholders/constituencies and customers—as shown in Fig. 7.2. Moreover, Tables 7.1, 7.2, 7.3 and 7.4 present four to eight example measurements, or metrics, which can be selected for each perspective in HEIs. There is no objective basis for the number of measures to include in any perspective, so if only two are identified, that is sufficient. A very large number of goals in each category may be awkward, but there are successful examples with more than eight in each perspective, and

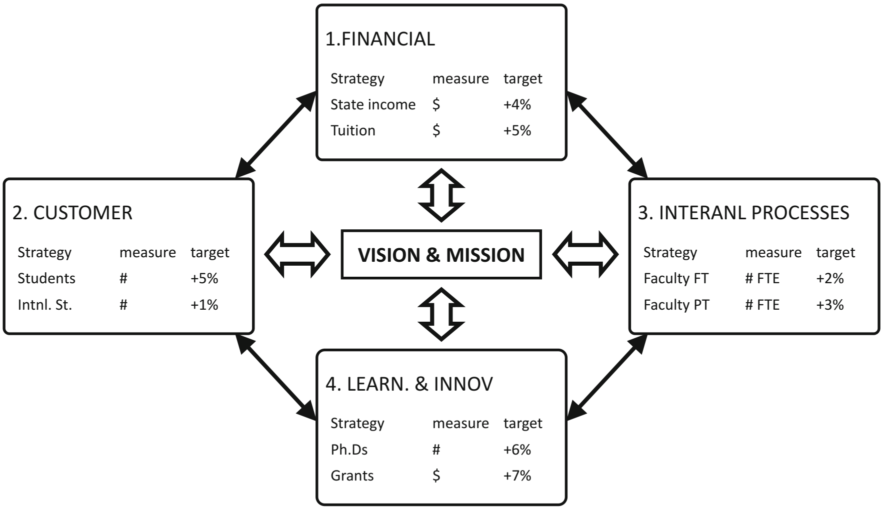

Fig. 7.2 BSC—four perspectives with university performance measures

there may be BSCs for different parts of the organization and different management levels resulting in many goals included in all the BSCs within an organization. Each metric has a specific and unambiguous target or set of targets. At the end of the measurement period, it should be clear as to whether the organization has successfully met the target for quantitative and qualitative measurement methods. Although BSC was designed for business organizations, it has been successfully applied to governmental and not-profit organizations such as Higher Education Institutions (HEIs). The goals in Fig. 7.2 are just illustrative. Readers should not evaluate them as a possible comprehensive set of measures for an HE or even as strong measures of the perspective in which they are listed.

Kaplan and Norton (2004) claim that successful implementation of BSC is based on *five principles*:

1. Translating the strategy to operational terms.
2. Involving all levels of the organization from the top level to the department level.
3. The strategy should be part of everyone every day.
4. Strategy should be continuous and long-run development process.
5. The top leaders should lead BSC strategic process.

Hafner (1998) was the first to report on the successful use of BSC at the University of California system, which includes nine campuses. The central vision was achieving excellence; around it the four BSC perspectives were measured for each perspective. Tangible and intangible goals were set, each with its performance measure.

In 2002 Lawrence and Sharma claimed that the use of business approaches, such as BSC, in HEIs caused by government cuts and strive for efficiency, turns

HE into a commercial good—commodification, where students become customers, and universities compete for students locally and globally. This managerialism and commercialism of HE degrade the value of HE. Nevertheless, they use BSC for strategic planning in a university in Fig. 7.2 to promote efficiency and accountability in the university. This concern about the BSC points to the importance of how an organization defined its mission and goals and how it establishes the goals and measures that are used in performance measurement and management system. For example, increasing students in Fig. 7.2 customer perspective would increase tuition and thereby help the financial performance perspective. However, if the admissions office recruited students below the admission standards just to boost tuition revenue, it may appear as good current period performance but could be leading to decline in the HE's reputation. This would be dysfunctional use of the BSC and suggests that the goals in Fig. 7.2 do not reflect all the goals of the institution, such as maintaining the quality of students.

Systems other than BSC, such as KPI (key performance indicators) and critical success factors, share this need to select measures that are consistent with their mission, and that motivate personnel to meet the individual goals in a manner that supports and advances the overall organization strategy. The developers of BSC have noted that just because one has a set of measures in each of the four perspectives does not in itself make a valid or effective BSC. To some extent, this could be viewed as a biased comment suggesting one needs to hire the inventors as consultants to do it right, the cynical view. However, it is important that the scorecard elements be fully reviewed by management to determine that the measures are appropriate and sufficiently comprehensive so that meeting the individual goals will help the organization achieve its mission and strategic objectives.

Unlike business organization, which maximize financial measures (e.g., profit and stock price), higher education concern is centered around academic measures. The starting point in the strategic planning process is the mission/vision statement of the HEIs, from which the objectives and measures are derived. The vision and mission used by HEIs, usually, are not focused on profit. Examples of HEIs vision or mission are: building the world's best university (Hafner, 1998); preparing students to become managers and leaders who will add value to their organizations and communities (Binden et al., 2014); becoming internationally recognized in research and teaching (Stewart & Carpenter-Hubin, 2001), etc.

7.2.1 BSC Perspectives in HE

BSC perspectives and measures are adapted to achieve the vision and mission of the HEI. Al-Hosaini and Sofian (2015) reviewed 29 publications with applications of BSC in HEIs. They list the main perspectives of each publication and found that most of the publications used the original four perspectives of business BSC suggested by Kaplan and Norton (1996), as shown in Fig. 7.2. However, four publications also use four perspectives, but their titles were adapted to HE. For example, Philbin (2011) used:

1. Financial
2. people development
3. Institute capability
4. Research output.

However, three publications used more than four perspectives.

Ruben (1999) suggested a HE dashboard with five major perspectives:

1. Teaching/Learning (program courses and student outcomes)
2. Service/Outreach (university, profession, alums, state, students, families, and employers)
3. Scholarship/Research (productivity and impact)
4. Workplace Satisfaction (faculty and staff)
5. Financial (revenues and expenditures)

Each major indicator was divided into sub-indicators, more tangible and multi-dimensional. Ruben indicated that the indicators and sub-indicators should be adapted to the specific institution and its relevant missions.

Hafner (1998) used five perspectives:

1. Human resources
2. Facility management
3. Environment health and safety
4. Information technology
5. Financial operations

Eltobgy and Radwan (2010) suggested six perspectives to evaluate HEI in Egypt Ministry of Higher Education via BSC, as follows:

1. Educational and learning excellence
2. Scientific research excellence
3. Community participation, environment development, and stakeholders
4. Human and material resources
5. Financial resources
6. Institutional capacity and quality management.

Morley et al. (2010) used Equity Scorecard, which provides each perspective relevant data by three social variables: gender, socioeconomic status, and age.

Another example is Chalaris et al. (2015), who suggested to use four other perspectives adapted to HEIs in the context of quality assurance:

1. Teaching and research work
2. Students–partners
3. Internal processes
4. Human and financial resources.

These differences in the perspectives used and even the order of listing perspectives are reflections of the need to adapt the BSC to the organization and the strategic goals. The adaptation is done within the organization.

7.2.2 Goals and Measures in HE for 4 BSC Perspectives

As shown in Sect. 7.2.1, most applications of BSC to HE use the original Kaplan and Norton BSC framework with the 4 perspectives as presented in Fig. 7.2. However, the specific goals within each perspective were adapted to HE. Tables 7.1, 7.2, 7.3 and 7.4 present examples of goals and measures for each of the 4 perspective as applied to HE. Perspective 1 includes financial goals; perspective 2 includes mainly degree programs and courses; perspective 3 includes mainly undergraduate and international student' programs; while perspective 4 includes mainly research outcomes and improved teaching (Hafner, 1998; Binden et al., 2014; Cullen et al., 2003, Ruben (1999), and others).

Table 7.1 *Financial* perspective[a]—strategies examples

Goal	Measure
Increase research income	Research income
Increase income from overseas students	Overseas income
Increase donations from local graduates	Donations income
Cost-effectiveness	Cost per student
Increase state funding level	State income
Keep budget in line	Budget target
Program funding	
Leverage	Ratio

[a]*Based on* Binden et al. (2014), Hafner (1998), Cullen et al. (2003), Ruben (1999), Ndoda and Sikwila (2014), *and others*

Table 7.2 *Customer* perspective[a]—strategies examples

Goal	Measure
Increase full-time under/grad. students	Undergrad. Students desired #
Enrolment rates by gender and program	Numbers and ratios
Increase number of international students	Desired # of international students
Develop partnership with foreign HEIs	# of foreign HEIs by quality
Students satisfaction	Courses/teachers evaluation
Degree completion time by program	# of years
Pass rates on professional exams	Rates and numbers
Improve students' job placement	# of job placements and their average salary/satisfaction
Raise the international profile of faculty	Rate and number

[a]*Based on* Binden et al. (2014), Hafner (1998), Cullen et al. (2003), Ruben (1999), Ndoda and Sikwila (2014), *and others*

Table 7.3 Internal organization perspective[a]—strategies examples

Goals	Measures
Integrated/new degree programs	Reducing # of non-core courses
Simplifying administrative support	Reducing # of reports and their length
Simplifying committees' structure/efficiency	Reducing # of reports and their length
Up to date academic curriculum	Every X years (X = 4 or else desired frequency)
Programs accreditation	Positive evaluation
University/program ranking	Various ranking scales

[a]*Based on* Binden et al. (2014), Hafner (1998), Cullen et al. (2003), Ruben (1999), Ndoda and Sikwila (2014), *and others*

Table 7.4 Learning and Growth Perspective[a]—strategies examples

Goals	Measures
Advancing research	# of publications; # of reports; # of patents acquired; # of consultancy reports;
International research level	# of publications in ISI; No. of scholar visitors; No. of awards; No. of conferences;
Increase number of research students	# of Ph.D. students
Improve teaching	Average evaluation of lecturers by peers
Employees satisfaction	Average evaluation
Skilled workforce	# of faculty with Ph.D. degree
Increase faculty efficiency	Student faculty ratio
Effective technology used	Investment in new technologies
Physical infrastructure	Area in sq. m. of built: Classes; Teaching labs; Research labs, etc.
Operating Practices Manuals Licenses and Certificates	Number
Strategic alliances reports	Number
External examiners' reports	Number
Library collections	Number of Books and Journals
IT hardware and licensed software	Number

[a]*Based on* Binden et al. (2014), Hafner (1998), Cullen et al. (2003), Ruben (1999), Ndoda and Sikwila (2014), *and others*

7.2.3 External and Internal Audiences in HE

Stewart and Carpenter-Hubin (2001) applied BSC to Ohio State University (OSU). They highlight the differentiation between externally and internally driven constituencies in HEIs and their concerns, focus, and data acquisition: The main three externally driven audiences in HE are:

1. Consumers: students and parents
2. Governing bodies: legislators and accrediting agencies
3. Revenue generators: Alumni, foundations, and donors.

The concerns of externally driven audiences are undergraduate education, graduate education, and the reputation of the HEI. Reflecting these audiences, the format of assembling data for planning are report cards, rankings, and indices.

The main *internally* driven audiences in HEI are:

1. Faculty
2. Academic administrators
3. Nonacademic administrators.

The concerns of internally driven audiences are resource allocation, priorities, and various organizational agendas. Their format of assembling data for planning is faculty or institutional committees and reports (ibid.).

7.3 Literature Review of BSC in HE

In 1999 Schneiderman wrote an article with the title: "*Why balanced scorecards fail*," during the same year Ruben (1999) suggested HE should use BSC for measuring university excellence. Evidently, Ruben's call for using BSC in HE was followed by many administrators, managers, and researchers as presented in Table 7.5.

This section summarizes the literature on BSC in HE over more than two decades (1995–2019). Counting the number of articles devoted to BSC in HE over time, we searched in Google Scholar Advanced Search and reported in Table 7.5 the counts. In the first column, two sets of keywords were used: "balanced Scorecard" and "higher education" (or university or college). During 1995–2019 the search located 368 papers with the search words in the title of the articles and 69,650 articles with the search words anywhere in the article. Evidently, as shown in

Table 7.5 Number of articles on BSC in HE[a] versus all BSC articles over time

Years	1. Articles' # with BSC and **HE** terms[a] in the article *title*	2. Articles' # with BSC and **HE** terms[a] *anywhere* in the article	3. Articles' # with BSC in article *title*	4. Articles' # with BSC *anywhere* in the article	5. Articles' # reviewed in Table 7.6
1995–1999	11 (3%)	1650 (2.4%)	885 (4.3%)	3270 (3.3%)	2 (3.3%)
2000–2004	42 (11.4%)	10,500 (15.1%)	4470 (22%)	16,200 (16.7%)	4 (6.6%)
2005–2009	81 (22%)	16,900 (24.3%)	5010 (24.6%)	22,300 (23%)	10 (16.4%)
2010–2014	114 (31%)	21,400 (30.7%)	5390 (26.4%)	35,000 (36%)	22 (36%)
2015–2019	120 (32.6%)	19,200 (27.5%)	4620 (22.7%)	20,400 (21%)	23 (37.7%)
Total	**368 (100%)**	**69,650 (100%)**	**20,375 (100%)**	**97,170 (100%)**	**61 (100%)**

Source: Author (Google Scholar advanced search assessed on February, 2020)
[a]*Search words: "balanced scorecard" and ("higher education" or "college" or "university")*

Table 7.5, the number of publications on BSC is growing over time significantly. Obviously, the second column shows huge numbers since it includes articles where BSC or HE could be negligible; for example, in some articles—only one reference is related to BSC. However, both numbers give indication on the growing use of BSC methodology (minimum of 368 articles), and its mention (69,650) in articles on BSC in HE during 1995–2019. The third and fourth columns of Table 7.5 provide the parallel data on the number of articles on BSC in general, not necessarily in the context of HE (during 1995–2019, counting 20,375 articles with BSC in their title, versus 97,170 articles with BSC anywhere in the article).

There are many publications on BSC in HE—368 articles where "balanced scorecard" appear in their title. Thus, in the next sub-sections' literature review, there is no attempt to cover all the articles on BSC in HE. Thus we covered only 61 articles in Table 7.6—covering a wide range of countries where BSC was directed to HE on various levels of HE. Included are more recent papers—from the last 5 years (2015–2019)—23 papers.

This review of the literature covers over 20 years (1998–2019) of applications of BSC in HE—as listed in Table 7.6 chronologically, highlighting three criteria for each article: Institutional level where BSC was designed for (Sect. 7.3.1), country of application (Sect. 7.3.2), and highlight and further analysis or other OR/MS methodology integrated with BSC (Sect. 7.3.3)—presented in columns 1, 2, 3, respectively.

7.3.1 Articles of BSC in Various Levels of HE Systems

As shown in Table 7.6, we cover a wide range of institutional levels: department, school, college, university, group of universities, national, and multinational as shown in Table 7.6. Most of the publications in this review address the university level, whether it is applied to a single university (20 articles), a group of universities (5 articles), the national level (15 articles), or multinational level (2 articles) in total 42 articles.

University level: In this review, 20 articles were devoted to BSC on the single university level, for example, Stewart and carpenter-Hubin (2001), Rompho (2008), Al-Ashaab et al. (2011), Sudirman (2012), Yakhou and Ulshafer (2012), Umayal Karpagam and Suganthi (2012), Ndoda and Sikwila (2014), Ahmad (2015), Chalaris et al. (2015), Pietrzak et al. (2015), Chimtengo et al. (2017), Hejazi et al. (2017), and El Junusi et al. (2019).

College Level: In this review two articles were devoted to BSC on the college level which is similar to the university level: Brown (2012) and Gamal and Soemantri (2017). Additional article was devoted to an Institute of Technology—by Chen et al. (2006).

School/Faculty Level: In this review, six articles were devoted to BSC on the school level by Cullen et al. (2003), Papenhausen and Einstein (2006), McDevitt et al. (2008), Al Kaabi and Jowmer (2018), and Lassoued (2018). Most of the articles

Table 7.6 Publications on BSC in HE

Author (year)	1. Institutional level	2. Country	3. Highlight/Further analysis
Hafner (1998)	Univ. of Cal.—9 campuses	USA	Cause and effect relationship
Ruben (1999)	University	General	Methodological
Bremser and White (2000)	Department (accounting)	USA	Top down BSC design experiment
Stewart and Carpenter-Hubin (2001)	University—Ohio State Univ.	USA	International Excellence
Cullen et al. (2003)	Faculty of Business	UK	Quality Management
Self (2003)	University library	USA	Focusing on 26 metrics
Chen et al. (2006)	Institute of Technology	Taiwan	Strategy map
Papenhausen and Einstein (2006)	Business School	USA	Survey
Asan and Tanyas (2007)	Eng. Manag. Grad. Prog.	Turkey	Hoshin Kanri method
Umashankar and Dutta (2007)	Private and public HEIs— - national	India	How to adapt BSC in India
McDevitt et al. (2008)	Business Sch. With 6 Dept.	USA	6 phase BSC process
Farid et al. (2008)	HEIs national	Iran	Methodological
Kettunen (2008)	University	Europe	Methodological, quality assurance
Rompho (2008)	University	Thailand	Questionnaire and strategy map
Beard (2009)	2 HEIs	USA	Comparison
Raghunadhan (2009)	Public and corpo. HEIs National	India	Comparison
Eltobgy & Radwan, 2010)	HEIs National	Egypt	Strategy Map and Radar chart
Morley et al. (2010)	HEI public and priv. National	Ghana and Tanzania	Equity scorecard
Al-Ashaab et al. (2011)	University	UK	Industry–university collaboration
Philbin (2011)	Institute in Univ. supported by Ind.	UK	Multidisciplinary institute, strategy map
Zangoueinezhad and Moshabaki (2011)	University	General	Methodological Fuzzy AHP
Aljardali et al. (2012)	HEIs National	Lebanon	Interviews and information sys.
Al-Zwyalif (2012)	Private univ. national	Jordan	Questionnaire Descript. statist.
Brown (2012)	College	USA	Strategy Map
Sudirman (2012)	University	Indonesia	Strategy map
Del Sordo et al. (2012)	HEIs National	Italy	Methodological

Taylor and Baines (2012)	4 HEIs	UK	Comparison by Interviews
Yakhou and Ulshafer (2012)	University	USA	Activity based costing
Umayal Karpagam and Suganthi (2012)	University	India	Strategy map
Jairak and Praneetpolgrang (2013)	Governance IT	Thailand	IT and importance anal.
Lewis et al. (2013)	Libraries in 4 universities	USA	Implementing BSC together
Maria et al. (2013)	Info. Comm. Tech dept.	Indonesia	Service dept. within a university
Sayed (2013)	30 HEIs	International	Review
Valderrama et al. (2013)	University by Department	Spain	DEA and strategy map
Weerasooriya (2013)	11 HEIs National	Sri Lanka	Questionnaire correlation, quality
Binden et al. (2014)	HEIs National	Malaysia	Review and suggest framework
De la Mano and Creaser (2014)	Libraries	International	Questionnaire and review
Ndoda and Sikwila (2014)	University	Africa	Questionnaire Factor anal.
Al-Hosaini and Sofian (2015)	Review	International	Table with 29 papers
Ahmad (2015)	University	Pakistan	Faculty Recruit.
Chalaris et al. (2015)	University	Greece	Quality assurance
Hladchenko (2015)	4 Universities	Germany and Austria	Comparison
Ismail and Al-Thaoiehie (2015)	University national	Saudi Arabia	Questionnaire
Pietrzak et al. (2015)	University	Poland	Strategy Map
Swierk and Mulawa (2015)	University	Poland	Strategy map and international review
Elola et al. (2016)	University national	Spain	Questionnaire, Strat. Map, structural Eq.
Lin et al. (2016)	Tech. and Voc. HEIs	Taiwan	Fuzzy Delphi, ANP, sustainable develop.
Mohammed et al. (2016)	Comparing 25 IHEs	Iraq	Questionnaire-descriptive stat. quality
Brown (2017)	School of Nursing	USA	Strategic planning process
Chimtengo et al. (2017)	University	Malawi	Questionnaire correlation
Gamal and Soemantri (2017)	Private college	Indonesia	Questionnaire multiple regression
Ozdemir and Tuysuz (2017)	87 universities national	Turkey	Fuzzy ANP and DEMANTEL
Reda (2017)	University and its academic dept.	General	Review, quality assurance

(continued)

Table 7.6 (continued)

Author (year)	1. Institutional level	2. Country	3. Highlight/Further analysis
Hejazi et al. (2017)	University	Iran	Questionnaire and strategy map
Usoh and Peterson (2017)	Public HEIs national	Indonesia	Questionnaire
Al Frijat (2018)	Accounting department	Jordan national	Questionnaire, regression analysis
Al Kaabi and Jowmer (2018)	Faculty of management	Iraq	Sustainable BSC
Fijalkowska and Oliveira (2018)	University	General	Review
Lassoued (2018)	College of Business	United Arab Emirates	SWOT
El Junusi et al. (2019)	University	Indonesia	Internationalization, ranking
Kiriri (2019)	University national	Kenya	Suggest national framework

Source: Author

were devoted to the school of business, where BSC is often taught. However, Brown (2017) used BSC for Nursing school.

Academic Department Level: In this review, only one article was devoted to a single academic department where BSC often taught—accounting: Bremser and White (2000). Although Al Frijat (2018) completed a questionnaire-based survey to assess on the national level the potential for improving accounting education in Jordan via BSC. Asan and Tanyas (2007) applied BSC to one Engineering Management Graduate Program. Some apply BSC to the whole university down to the department level, for example, Valderrama et al. (2013).

Service Department Level: In this review three articles were devoted to service departments: Self (2003) applied BSC for a university library. Lewis et al. (2013) report about the cooperation among libraries in four USA universities on implementing BSC. De la Mano and Creaser (2014) wrote a review on libraries worldwide that use BSC for measuring performance and strategic planning—they used a questionnaire; their sample includes 49 libraries—including academic libraries. Maria et al. (2013) used BSC for the Information communication technology service department in a university in Indonesia to improve its performance.

Philbin (2011) used BSC for strategic planning of a research institute serving various departments in a university supported by the industry.

Sometimes BSC is applied for a specific issue. For example, Al-Ashaab et al. (2011) used BSC to measure the impact of *industry-university collaboration*. Applications of BSC devoted to specific functions within HEIs were given in the literature: Ahmad (2015) applied BSC to faculty recruitment to improve the least developed departments of HEIs in a region.

Several Universities: BSC was devoted to several universities by five articles: Hafner (1998) in the nine State Universities of California. Ozdemir and Tuysuz (2017) applied BSC in 87 universities in Turkey. Weerasooriya (2013) used BSC for 11 universities in Sri Lanka. Hladchenko (2015) compared the use of BSC in two Austrian and two German Universities. Mohammed et al. (2016) used questionnaires for 25 HEIs in Iraq.

National Level: BSC was devoted by 15 articles to HEIs on the national level, for example, Umashankar and Dutta (2007) for India, Farid et al. (2008) for Iran, Eltobgy and Radwan (2010) for Egypt, Aljardali et al. (2012) in Lebanon, Al-Zwyalif (2012) for Jordan, Del Sordo et al. (2012) for Italy, Binden et al. (2014) for Malaysia, Ismail and Al-Thaoiehie (2015) for Saudi Arabia, Elola et al. (2016) for Spain, Usoh and Peterson (2017) for Indonesia, and Kiriri (2019) for Kenya. Mostly on the university level, some were applied to public HEIs, some for private, and some for both. Lin et al. (2016) applied BSC to technical vocational HEIs in Taiwan.

Multinational Level: Kettunen (2008) suggested to use BSC for evaluating European universities quality performance. Morley et al. (2010) designed an equity scorecard for Ghana and Tanzania HE.

7.3.2 Country of BSC Applications

USA is the leading single country in the applications of BSC in HE. Swierk and Mulawa (2015) listed 39 universities that used BSC, of which 33 universities were in the USA—they extended the list of Rompho (2008), which included 22 universities which used BSC, of which 19 were in the USA.

We made an effort to cover variety of countries in this partial review (of 61 articles in Table 7.6), 11 articles reflect applications of BSC in USA HEIs (for example, Hafner, 1998; Bremser and White, 2000; Stewart and Carpenter, 2001; Beard, 2009; McDevitt et al., 2008; Brown, 2012, 2017; Lewis et al., 2013), which is far more than any other single country in our review.

BSC was applied for HEIs in many other countries. Several publications suggested various frameworks to fit the application of BSC to specific countries. For example, Farid et al. (2008) in Iran, Raghunadhan (2009) in India, Morley et al. (2010) in Ghana and Tanzania, Eltobgy and Radwan (2010) in Egypt, Del Sordo et al. (2012) in Italy, Al-Zwyalif (2012) in Egyptian private universities, Aljardali et al. (2012) in Lebanon, Binden et al. (2014) in Malaysia, Chalaris et al. (2015) in Greece, Hladchenko (2015) in Austria and Germany, Ismail and Al-Thaoiehie (2015) in Saudi Arabia, Pietrzak et al. (2015) in Poland, Mohammed et al. (2016) in Iraq, Hejazi et al. (2017) in Iran, Usoh and Peterson (2017) in Indonesia (public HEIs on the national level), and El Junusi et al. in Indonesia (in a specific university)), Ozdemir and Tuysuz (2017) in Turkey, Ismaand Kiriri (2019) in Kenya. Umashankar and Dutta (2007) suggests to use BSC in India. Raghunadhan (2009) discusses the use of BSC in Indian public universities, and Umayal Karpagam and Suganthi (2012) reports about the application of BSC in a specific university in India. Weerasooriya (2013) examined the performance of entire management faculties/schools in Sri Lankan Universities.

In summary, grouping articles in Table 7.6 by continent: 27 articles were devoted to Asia, 11 articles to Europe, 11 to America (actually the USA), and 5 to Africa—the rest of the articles are methodological or reviews of BSC in HE (7 articles).

7.3.3 BSC Integrated with Other Methodologies

Some applications of BSC in HE are combined with additional methodologies as given in the last column of Table 7.6.

Questionnaires and statistical methods were used in many studies often on the national level (over 13 articles). Rompho (2008) used questionnaires for HEIs in Thailand—**correlations** were used to verify the relationships of the strategy map's elements. Al-Zwyalif (2012) performed a study aims at identifying the Jordanian private universities' awareness of the importance of the implementation of BSC—a questionnaire was used to verify several hypotheses via ***t*-test;** also **descriptive statistics** was presented. Ndoda and Sikwila (2014) used questionnaires in Africa, utilizing **factor analysis**. Elola et al. (2016) used questionnaires in Spanish private and public HEIs, utilizing **structural equations** for strategy map. Al Frijat (2018) used questionnaires and statistical analysis for accounting departments in Jordan. Others also used questionnaires: Ismail and Al-Thaoiehie (2015) in Saudi Arabia, Mohammed et al. (2016) in Iraq.

Questionnaires were also used on the single institution for extracting evaluations from its constituencies. For example, Chimtengo et al. (2017) evaluated the correlations between each of the 4 perspectives and the performance evaluation of their constituencies at a university in Malawi. Hejazi et al. (2017) used questionnaire for a university for analyzing a strategy map.

Strategy Map is a simple graphic that shows a logical, cause-and-effect connection between strategic objectives—how the various perspectives: financial, customer, internal process, learning, and growth are linked, and how they create a balance between these perspectives to focus the organization on meeting its strategy objective (Kaplan and Norton (2004). Examples of applying BSC with strategy maps were reported in Chen et al. (2006), Eltobgy and Radwan (2010), Philbin (2011), Brown (2012), Pietrzak et al. (2015), Elola et al. (2016), Hejazi et al. (2017), and others.

Radar chart, presenting the values of the various objectives of BSC, was used by Eltobgy and Radwan (2010).

SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was integrated with BSC by Lassoued (2018) Emirates College of Business in Abu Dhabi.

Fuzzy AHP (Analytical Hierarchy Process, by Saaty, 1994) was suggested by Zangoueinezhad and Moshabaki (2011) in their methodological article for evaluating the performance of HEIs annually based on the knowledge-based indices of the 4 BSC perspectives.

Fuzzy ANP and DEMANTEL were used by Ozdemir and Tuysuz (2017), which integrated BSC with Fuzzy ANP (Analytic Network Process—which enables to prioritize the strategies, it is a generalization of AHP by Saaty, 1994) and fuzzy DEMANTEL (Decision Making Trial and Evaluation Laboratory—which determine the relationships among the strategies). The model was designed for Turkey HEIs—an application to 87 HEIs is reported.

Fuzzy Delphi and ANP were applied by Lin et al. (2016) to technical and vocational HEIs in Taiwan for achieving sustainable development competencies, considering uncertainty.

Sustainable BSC (SBSC) was also used by Al Kaabi and Jowmer (2018) at the Faculty of Management and Economics at Mustansiriyah University in Iraq. The sustainable aspect they suggest is, for example, attract high-quality students, develop academic excellence and innovation, and building funds for donations.

DEA (Data Envelopment Analysis) measures the efficiency of units based on their multiple inputs and multiple outputs (Charnes et al., 1978). DEA combined with BSC have been used by Valderrama et al. (2013), where the decision-making units are academic departments.

ABC—Activity Based Costing (assigning more overhead costs into direct costs compared to conventional costing) was combined with BSC by Yakhou and Ulshafer (2012) for strategic planning in HEIs.

Asan and Tanyas (2007) presented a methodology that integrates the BSC with *Hoshin Kanri* (ibid.), a seven-step process-based approach used in industry from the corporate level (strategy) through the mid-level (tactics), down to the floor level (operations).

7.3.4 BSC Use for Quality Assurance

Most of the articles presented here use BSC for strategic planning in HEIs by settings multi-dimensional financial and nonfinancial targets; namely, sets of quantitative academic measures of the desired future performance of HEI in relation to its current performance (see examples in Table 7.1). However, several studies used BSC for quality assurance (QA) purposes for various levels of HE. For example, Kettunen (2008) suggested to use BSC on the international level for evaluating European universities quality performance. Cullen et al. (2003) applied BSC for quality assurance at the school level (school of business). Chalaris et al. (2015) applied BSC for QA on the university level for HEIs in Greece for the national QA process. They highlight the importance of using management information systems to support the process of BSC in HEIs. Mohammed et al. (2016) suggested to use BSC for QA of HEIs in Iraq on the national level.

Beard (2009) gives examples of two HEIs which used BSC successfully and even won Malcolm Baldrige National Quality Award of the European Foundation for Quality Management (EFQM) and BSC.

Reda (2017) highlights the congruence and role of BSC in QA practices in HEIs. He claims that in order to have meaningful QA evaluation, there is a need to emphasize quality measures in each of the 4 perspectives. Three areas that are noted as important for QA in HE: 1. teaching and learning, 2. research, and 3. community services. Each area within each prospective has its specific objectives, and for each objective its measures, targets, and initiatives.

7.4 Advantages and Disadvantages of BSC in HE

Many wrote about the advantages and disadvantages of BSC in HE. Already in 2002, Lawrence and Sharma claimed that treating HE as a private good and students as customers is a potential degradation of HE function in society. Moreover, through the application of market-based methodologies, as BSC, to promote efficiency in HE, the very essence of HE is jeopardized. Nevertheless, the use of BSC in HE increased greatly over the years (as shown in Table 7.5).

Taylor and Baines (2012) interviewed leaders of four UK representative HEIs who used BSC. They provide a critique of BSC in HE. Its advantages are:

1. BSC is tied directly to the institutional goals and plans.
2. BSC provides link to all levels of the institution.
3. BSC is simple.
4. BSC provides "lag" (past) and "lead" (future)performance measures.

The disadvantages of BSC in HE are:

1. To imbed BSC in all levels of the institution significant work/cost/time are required.
2. The 4 perspectives are not general but require local adaptation.

Overall, they concluded that BSC was a success—they all saw the Scorecard as a methodology to integrate overall corporate strategy with operational planning across the institution or at the level of individual departments and schools (ibid). This success is also due to the dedication of very top academic/administrative leaders of each of the HEIs involved and the quality assurance process required by state authorities in the UK. They referred to a survey of the UK Committee of University Chairmen from 2004, which reported that 20 HEIs regularly monitored performance against their corporate plan (ibid). The success of the performance measurement approach in general and BSC is dependent on high-quality management information systems.

Sayed (2013), in a critical review of the applicability of BSC to HEIs, based on a review of 30 universities around the globe, found that universities are limited in their ability to mobilize resources as BSC often recommends. Moreover, the adaptation of BSC by university administrators is slow, often due to their insufficient background, and somewhat altruistic mission.

7.5 Summary and Conclusions

BSC is a strategic tool adapted from business by the HEIs' administration and other stakeholders to capture the multi-dimensional aspects of universities' performances, financial and no-financial, mainly for strategic planning. Beyond strategic planning, BSC has been used for comparison/benchmark and quality assurance of HEIs. As shown in our review, BSC is spread worldwide.

Our literature review, on BSC in HE, is, to our knowledge, the largest and most comprehensive so far—covering over 60 articles devoted to BSC in HE. We acknowledge that there are many other HE articles not included in this review and hope the value of this review will help HE managers consider whether BSC would help them achieve their institution's mission. We also believe that while there are limitations and hurdles to adapting BSC, the related question is what method will be used to steer the institution to meeting its mission and would BSC be advantageous compared with the current methods or others under consideration. Our somewhat systematic lists the articles in a table chronologically, classifying the articles by the level of the HEI, the country of application, the highlight of the paper, and other methodology used in conjunction with BSC. While we covered only 61 out of 368 papers in Google Scholar, where HE and BSC are mentioned in their title, there are many more where HE and BSC are mentioned anywhere in the article—69,650 articles.

Our findings show that BSC growth in HEIs is consistent over the last 20 years. However, the rate of growth in the number of publications is moderate in the last five years. The number of applications (which are often not reported in the literature) may continue to grow due to many articles in which BSC is the suggested framework that should be used on the national level in many countries, mainly for quality assurance. Based on our review, it appears that BSC has been implemented mainly at the university level. Statistical analyses with questionnaires were the most used methodology in conjunction with BSC. We believe there is great potential for increasing the integration of BSC with OR/MS methods such as, DEA for measuring academic efficiency, ranking methods, and TQM (total quality management) for quality assurance, simulation, and big data. These OR/MS methods generate measures that can be included in the performance measures in the four perspectives of the BSC and can also drive the initiatives to help an organization achieve the goals related to specific performance measures such as the use of DEA to measure and manage operating efficiency.

Educational costs and benefits need to be considered while implementing performance management (Chen et al., 2006). With the budget pressure, competition, and ranking in HEIs, the moves in the direction of performance management are inevitable. BSC aims to provide a concise solution to manage a complex process of assessment, evaluation, and reflection at various levels within the institution and often in relation to other HEIs. Thus, for the success of implementing BSC, there is a need for a unified information system to utilize the BSC data collection overtime on all levels of HEIs: department level, school level, university level, and national level.

Ratnaningrum et al. (2020) reviewed the BSC literature from 71 articles published in Q1 rank Scopus indexed journals in the areas of business, management, and accounting (21 journals). Out of 45 empirical papers, 5 were devoted to the public sector, of which 2 were applied to HE (Asan & Tanyas, 2007 and Lawrence & Sharma, 2002). They conclude that, although BSC has limitations, their findings show that BSC is beneficial enough. It is reinforcing the view that the BSC remains worth considering for a performance management system.

The numerous BSC applications to HE underlines two paramount characteristics of the BSC that we offer at the conclusion of this study along with one general observation:

1. BSC is a comprehensive performance measurement and management methodology that can be adapted to organizations at various levels, from a multi-site HE system to individuals within these organizations. A simple reminder of this is that the initial corporate BSC model has financial as the primary perspective

but that a not-for-profit HE can revise and adapt the BSC to include customer or another perspective as primary and define customer as students as well as other stakeholders such as donors and government funding sources. This is demonstrated by the wide diversity of HE applications worldwide.

2. The effectiveness of the BSC in helping HE (and any organization) is highly dependent on the way it is developed and applied to HE and the way it is used in these organizations. The performance measures and targets in each perspective need to be congruent with the mission and strategic goals. The measure needs to clearly reflect the critical elements, including lagging indicators such as financial results reflecting past performance and leading measures to drive future performance. In addition to the financial measures and other common quantitative measures, quality measures, qualitative measures, and other measures critical to the success of the organization can and should be incorporated into the perspective. There is no requirement that any one perspective, such as financial, dominate the BSC if that perspective is not a key element of the mission. Senior management leadership and support are critical in adapting the BSC. Performance evaluation and reward systems can be tied to the achievement of BSC target goals. Under these conditions, the BSC can motivate results that advance the organization consistent with its strategic goals and mission as it has with many other organizations.

   Observation—The BSC can be highly effective and add much value. It has been noted that one very valuable way for management to discuss and evaluate organization strategy and mission is to focus on the four perspectives and the measures.

   We fully acknowledge the effectiveness of the BSC when properly applied and adapted to an organization and specifically to HEI and the evidence of many users reported in the literature. However, we are not suggesting that the BSC is the only comprehensive methodology. Other comprehensive performance measurement systems that recognize and incorporate the multiple dimensions for which management is accountable can also be effective, and in all cases, the way they are adapted and used has a significant influence on how well they benefit the organization.

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Chapter 8
System Analysis of Technology Transfer Policies and Models in Higher Education

Arnon Bentur, Daphne Getz, and Oshrat Katz Shacham

Abstract The current chapter presents a critical evaluation of the modes of knowledge and technology transfer from academia, based on the evaluation of data which spans over the last three decades and a case study of technology transfer in the fields of artificial intelligence, data science, and smart robotics. A need emerges for reevaluating and revisiting university policies with regards to its third mission. Such policies should be set to guide the activities of the Technology Transfer Offices of universities, to balance between technology commercialization, which is more linear in nature, and technology transfer with industry, which is more holistic, interactive, and entrepreneurial in nature. Greater emphasis on technology transfer and more intimate cooperation with industry may result in an increase in research funding as well as in improved level and significance of research. More than that, such policies are more likely to be met by support of the academic faculty, and they should be an inherent part of the development of entrepreneurial activities in universities, which include education that is suitable to the needs of the industry and society, as well as more significant and effective research. It is recommended that the achievements of the universities regarding the third mission should be quantified and ranked on the national and international levels. They should be based on multiple indices to reflect various modes of achieving such goals, in view of the range of mechanisms of university–industry interactions.

Keywords Technology transfer · Commercialization · Higher education

A. Bentur · D. Getz (✉) · O. K. Shacham
Samuel Neaman Institute, Haifa, Israel
e-mail: bentur@technion.ac.il; daphne@sni.technion.ac.il; oshrat@sni.technion.ac.il

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8.1 Introduction

The most valuable contribution of academia to society and economy is the human capital: engineers and scientists, educated at the universities, as well as the open knowledge produced through fundamental research. These are, perhaps, the most important roles of academia to the knowledge-driven modern society of the twenty-first century. They are directly related to its core missions of education and research.

In the midst of the previous century, following the Second World War, the indirect and tacit process of innovation was considered to be sufficient for transferring knowledge to industry via an innovation process described by Bush (1995) as a linear process, made up of the following stages:

$$Basic\ research \rightarrow Applied\ research \rightarrow Development \rightarrow Production/Products$$

This linear innovation model is no longer adequate, since the interactions between basic research, applied research and development are much more complex, with the boundaries between them becoming blurred, as is the case with boundaries between engineering and scientific disciplines.

This change is the driving force for reevaluation of the role and mode of operation of universities, from one where the only two missions were education and research, to one where a "third mission" is added, labeled sometimes as "technology transfer," whereby the university should be actively and directly involved in getting its know-how into the industry and society. This should take place without relying only on the tacit and spontaneous influences associated with the core missions of education and research. The significance of this approach shows up in discussions that highlight the need for universities to be much more entrepreneurial, with the term "entrepreneurial university" being frequently used (U.S. Department of Commerce, 2013; Eesley & Miller, 2018; Etzkowitz & Leydesdorff, 2000; Gibb, 2012; Graham, 2014; Ouchi, 2011; Rauw et al., 2014; UCLA, 2011; Vaquero-García et al., 2016; Yoon & Lee, 2013).

The current chapter is based on a critical evaluation of the modes of knowledge and technology transfer from academia (Bentur et al., 2019), based on the evaluation of data that spans over the last three decades and case study of technology transfer in the fields of artificial intelligence, data science, and smart robotics.

8.2 The "Third Mission" and the Entrepreneurial University

The implementation of the "third mission" is quite a challenge, as it requires new modes of action to be taken, involving a cultural change. All of these should be carried out with care, to make sure that they do not come at the expense of the contribution to society which is based on the first two core missions of education and research. In the case of technological universities, the third mission is accomplished by developing special modes of interaction, to provide direct transfer of technology to the industry. This involves a range of mechanisms, all falling under the umbrella of "university–industry relations."

The active steps that a university must take in the transfer of know-how, which is an essential part of its expected third mission, requires a holistic approach, which includes several components, in addition to the basic knowledge dissemination, such as the ones presented in Fig. 8.1.

The items in Fig. 8.1 have been proposed by the European Commission (Finne et al., 2009), to quantify knowledge transfer from public research organizations in Europe. They are grouped here into three categories:

Knowledge dissemination: The traditional role of universities, such as open scientific publications, conference meetings, education of engineers and scientists.

Technology Transfer: Direct interactions between university researchers and industry through mechanisms such as contract research, joint research and consulting, government subsidies to generate generic technologies by interaction between university and industry partners, or consortium of several universities and industries.

Technology Commercialization: Dominant mode of action of the Technology Transfer Offices (TTO) and Technology Licensing Offices (TLO) of universities, whereby faculty are required to disclose inventions and the TTO/TLO unit is in charge of commercializing it by modes such as patenting followed by licensing and creation spin-offs.

The terminology currently used in universities, "Technology Transfer," reflects essentially the efforts to commercialize universities' intellectual property (IP), and it is somewhat misleading, as it implies that this is the only mode of transfer. The transfer of know-how involves all three categories in Fig. 8.1 whereas the proactive technology transfer associated with the third mission of universities is based on both, "technology transfer" and "technology commercialization," as defined above.

The Bayh–Dole Act of 1980 in the USA was enacted based on the perception that university ownership of IP, produced by publicly funded research, will result in mobilizing universities to be proactive in utilizing the fruits of research for the benefit of society, consistent with the idea of encouraging universities into being active in promoting the "third mission." Many of the developments since then, at the universities, such as the establishment of TTOs and TLOs, as well as the increase in patenting activities, have been ascribed to this Act. However, later discussions have placed doubt on this view (Kenney & Patton, 2009; Sampat, 2006; Valentin & Jensen, 2007), suggesting that the Bayh–Dole Act was accelerating processes that were already incubating.

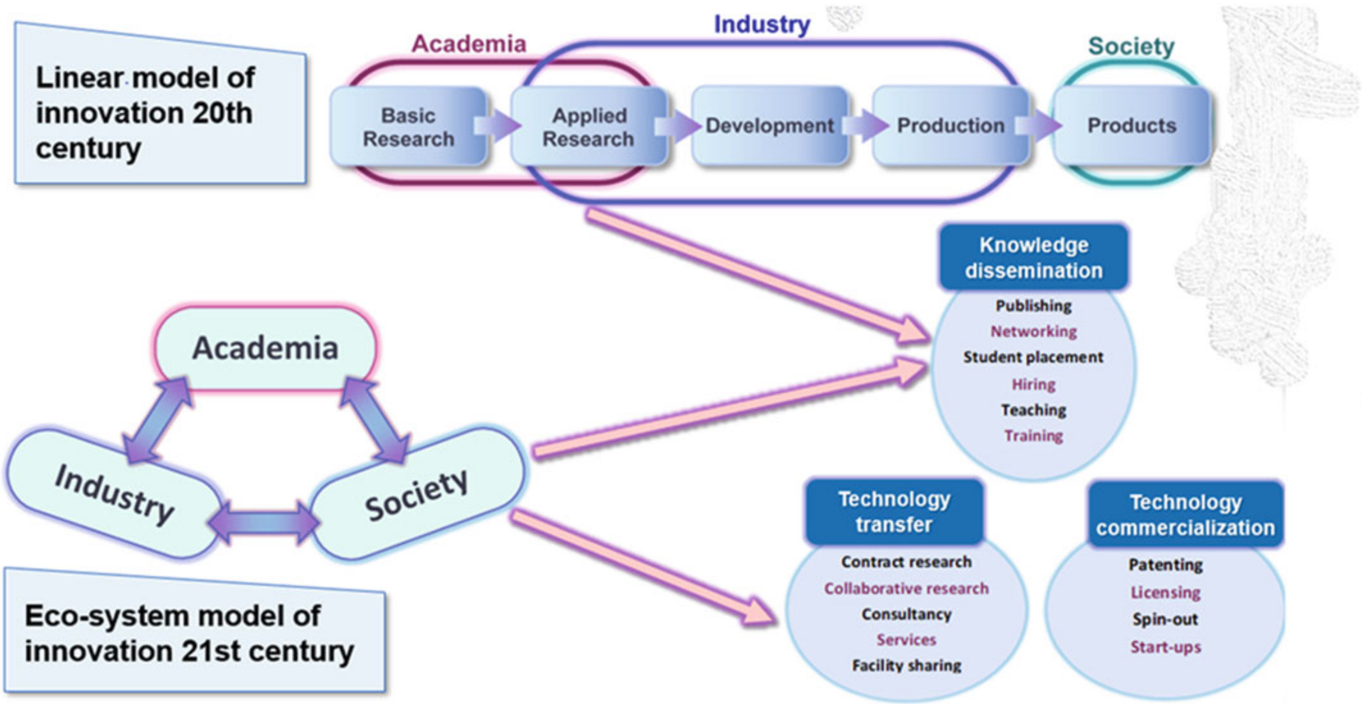

Fig. 8.1 Mechanisms of knowledge dissemination, technology transfer, and commercialization (Bentur et al., 2019)

8.3 Technology Commercialization

The mechanism of technology commercialization is to a large extent linear in nature, involving successive steps:

$$Scientific\ discovery \rightarrow Invention\ disclosure \rightarrow$$
$$Evaluation/patent\ application \rightarrow Licensing/startup\ formation$$

The evolution with time of the commercialization activity is presented in Fig. 8.2 and expressed in terms of the number of TTOs/TLOs established in US universities over time. The rise in the number of TTOs/TLOs formed during the 1990's is related by some to be the result of the Bayh–Dole Act enacted in 1980.

Over that time period, there has been a continuous increase in licensing activities and commercialization income, which accompanied an increase in research funding. Thus, an in-depth analysis of the trends cannot be simply interpreted as a rise in the intensity of commercialization activities and benefits, and it should rather be analyzed taking into account the rise in research expenditures, as highlighted in Fig. 8.3. The data in this figure shows that the commercialization income remained practically constant relative to research funding over the last two decades.

Analysis of the nature of IP indicates that most of the commercialization income is coming from a small fraction of the inventions. The commercialization income is largely obtained from running royalties and not cashed in equities (Love, 2014; Merrill & Mazza, 2011; Reslinski & Wu, 2016).

The distribution of commercialization of income between US universities during the period 1991–2017 is presented in Fig. 8.4 in relative terms, % of R&D

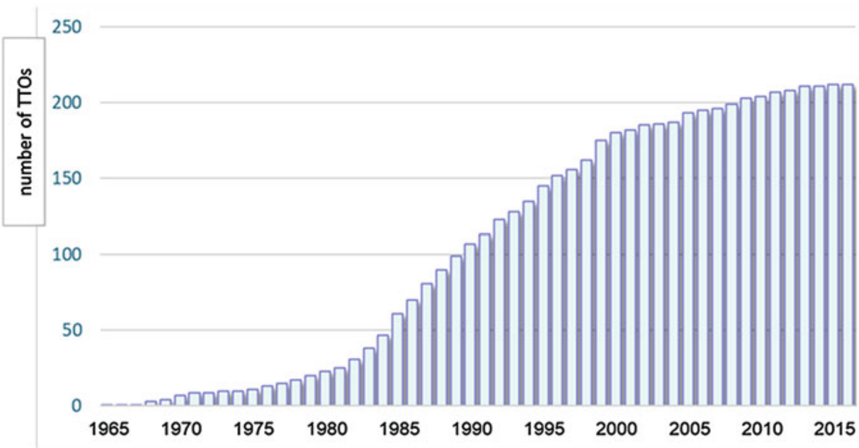

Fig. 8.2 Development of TTOs in US universities, 1965–2015 (Bentur et al., 2019), based on AUTM data, extension of data presented by Valdivia (2013)

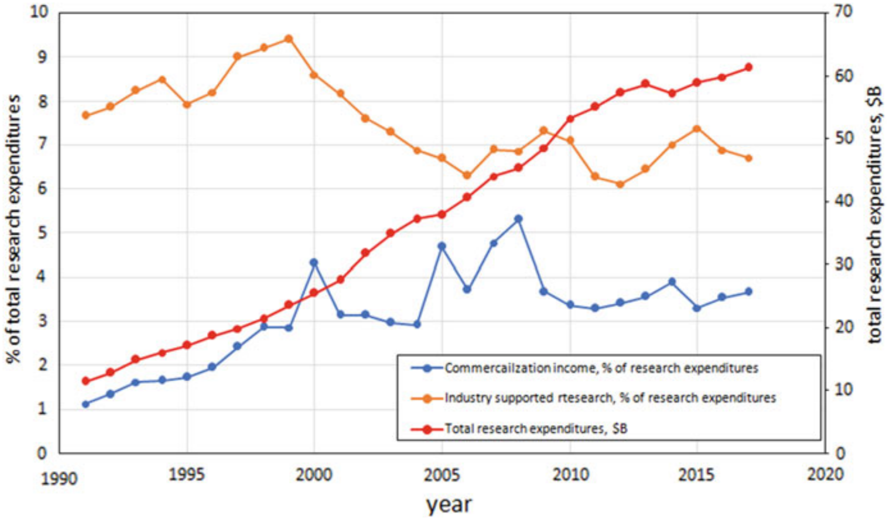

Fig. 8.3 Trends of total research expenditure and relative values (% of total research expenditure) of research funded by industry and commercialization income for US universities, reported in the AUTM surveys, 1991–2017 (Bentur et al., 2019), based on AUTM data (AUTM data surveys: the number of universities surveyed increased from 72 to 115 during 1991–1993, thereafter increasing at a mild rate up to 160 in 2003, and from there on remained almost constant, to 163 in 2017)

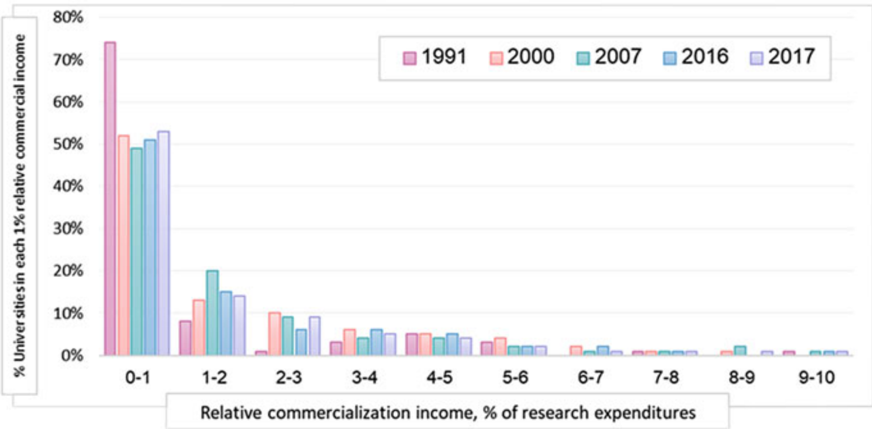

Fig. 8.4 Distribution of commercialization income in relative terms, % of research expenditures, over the period 1991–2017 (Bentur et al., 2019), based on AUTM data

expenditures. The data indicates that most universities earn only a few percentages of income relative to their R&D expenditures, with 50% of the universities less than 1%, and about 85% less than 5%.

The distribution in income presented in Fig. 8.4 has not changed in almost 20 years (Bentur et al., 2019).

This financial data indicates that only a few of the inventions are commercialized, and only a few of the latter lead to income of some significance. In addition, only a few universities earn significant income from IP commercialization. Valdivia (2013) analyzed such trends and demonstrated that commercialization income is derived mainly from blockbusters, and the probability of such blockbusters is dependent on the overall research expenditures of the university. It was also shown that the blockbuster income from commercialization tends to be skewed also toward life sciences, as shown for data collected by Nature Biotechnology (Huggett, 2014).

8.4 Technology Transfer

8.4.1 Mechanisms

The flow of know-how from university research to industrial development and innovation has many avenues with considerable impact, as has, for example, been highlighted by Cohen et al. (2002) and quantified based on a survey of industries, Fig. 8.5.

It can be seen that mechanisms which are defined as technology transfer in Fig. 8.1 are relatively high on the list in Fig. 8.5: informal interactions, consulting, contract research, and cooperative R&D projects. They are much higher on the list than the Technology Commercialization mechanisms: patents and licenses.

The impact of “Technology Transfer” mechanisms is largely indirect and the IP created is either jointly owned by the university and industry or industry only. This is in contrast with the “Technology Commercialization” mechanism where the output can be more readily quantified in terms of the number of patents, licenses, and income. Thus, the quantification of “Technology Transfer” is based, usually, on inputs (e.g., funding of research projects) rather than outputs.

The impact of “Technology Transfer” is the result of many mechanisms, with some interacting with each other. Some are formal mechanisms that can be readily identified, e.g., research contracts, and some are informal, driven by human interactions between researchers from academia and industry who cooperate on specific research. Thus, there is a need to resolve such mechanisms first and thereafter to try quantifying them.

Schaeffer et al. (2018) investigated the interaction of mechanisms with the notion that there are significant informal interactions that have value and should be considered, and the presence of a contract, defining the formal relation, is not sufficient to evaluate the impact of the interactions. There are formal interactions that follow the linear model of innovation, where there is little surrounding tacit knowledge transfer, such as patent licensing agreements, and there are ones where continued and intense personal interactions may take place, such as in industrial research contracts, where face-to-face interactions are quite common.

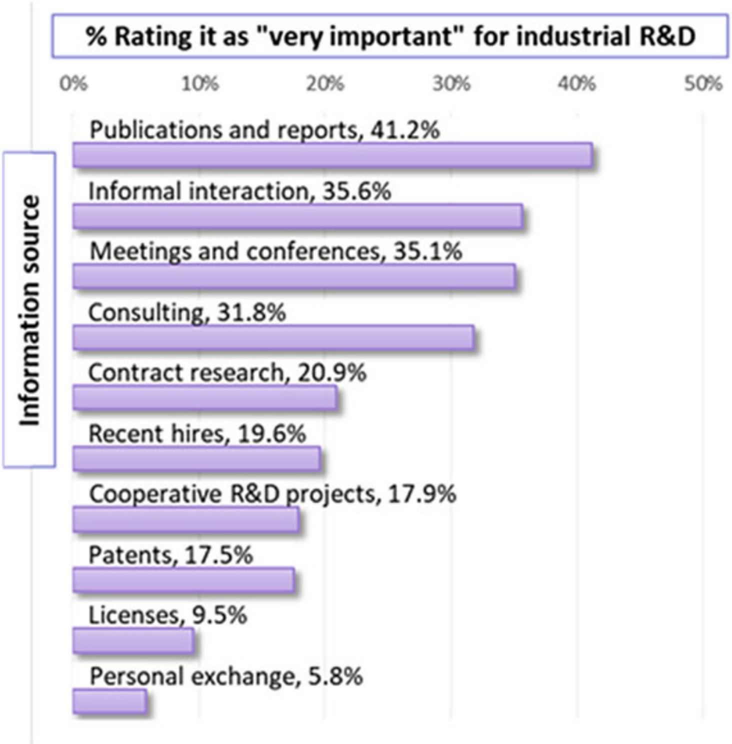

Fig. 8.5 Importance to industrial R&D of sources of information generated in public R&D (Bentur et al., 2019), adopted from Cohen et al. (2002)

These case studies led Schaeffer et al. (2018) to identify strong complementarities between the formal and informal mechanisms, which reinforce one another, consistent with the report of Grimpe and Hussinger (2016). Informal links often result in the establishment of formal interactions such as research agreements and startup formation. Formal relations are often followed by personal interactions which result in additional collaborations. It is the cumulative effects of these interactions which lead to efficient technology and knowledge transfer, and this is fed by good science and evolves into activities of mixed teams of academic and industrial researchers. In many ways, this is an entrepreneurial activity whereby the university needs to develop wider strategies and modes of operation for its TTO/TLO, beyond the conventional mode of operation, where TTO/TLO staff is considered just as intermediaries in charge of patenting, licensing and establishment of new companies.

The survey carried out by Link and Siegel (2005) indicated that faculty members who are active in securing research grants are preferring the informal modes of technology transfer. This may imply that there is tension between the grant-active faculty and university incentives to take part in formal technology transfer modes, perhaps because the former is more basic in nature and the latter are more applied.

8.4.2 *Quantification Mechanisms of Technology Transfer*

Various attempts have been made to quantify these mechanisms, each of them on its own, and a cumulative index incorporating all of them. Some examples highlighting different modes of quantifications will be presented here.

The most direct index to quantify the intensity of technology transfer associated with university–industry relations is the volume of research carried out by universities in cooperation with industry, based on industry funding. This is best described in terms of the proportion of research supported by industry relative to total research funding, as shown in Fig. 8.6 using OECD data-base for OECD countries, USA and Europe, since 2000.

It can be seen that over the period since 2000, the proportion of industry-funded research in academia has not increased and even showed a slight decline, especially in the USA.

The trends for industrial-supported research, commercialization income, and total research funding for the US universities included in the AUTM survey are presented in Fig. 8.3. Total research funding has been increasing continuously over the years. However, the relative proportion of industrial funding has been decreasing while the relative commercial income seems to be stable since 2000, although very variable over this period. Such trends imply that the intensity of technology transfer and technology commercialization since 2000 have been stable at best or even declining, contrary to the general belief that they have been intensifying.

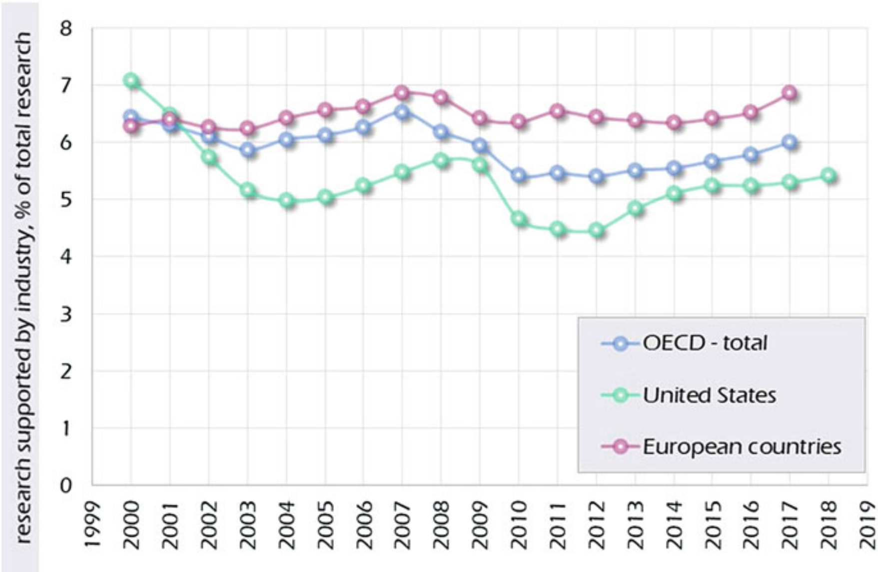

Fig. 8.6 Proportion of research supported by industry in academia, average values in USA, Europe, and OECD countries (Bentur et al., 2019), OECD data

The distribution of relative industrial research funding in the top 100 US universities indicates that there are very few universities with more than 10% industrial funding, falling quickly to levels below 10% for most universities in the top 100 list (AUTM data; Bentur et al., 2019).

The trends above clearly highlight that the intensity of university–industry relations as quantified in terms of industry-funded research have not been intensified over the years, in spite of the national and international programs and policies to encourage more industrial research at universities.

Since industrial-supported research is not the only mechanism for university–industry relations and technology transfer, it is of interest to explore and quantify other mechanisms.

Tijssen et al. (2016) defined seven indices by which to characterize technology transfer and rank universities accordingly (Table 8.1).

Table 8.1 Indices quantifying university technology transfer (Bentur et al., 2019), after Tijssen et al. (2016)

Index	Description
%UIC	Share of university–industry co-publications (as a % of research publication output)
%MA UIC	Share of multiple-affiliation university–industry co-publications with at least one author listing a university address and a company address (as a % the total UIC output)
%LOCAL UIC	Share of university–industry co-publications with at least one partner company within a 50-km range of the city in which the university is located (as a % the total UIC output)
%DOMESTIC UIC	Share of university–industry co-publications with at least one partner company located in the same country as the university (as a % of the total UIC output)
%CO-PATENT	Share of granted international patents with a co-assignee from the business sector (as % of all granted international patents)
%NPLR share	Share of non-patent literature references, i.e., publications cited in the reference list of international patents (as a % total research publication output)
%NPLR–HICI	Share of non-patent literature references within the world's top 10% most highly cited international patents across all technology areas

Data sources used by Tijssen et al. (2016) to quantify these indices included:

- Leiden Ranking 2014 (publication years 2009–2012) for %UIC
- CWTS (publication years 2009–2012; Web of Science) for %MA UIC
- U-Multi-rank 2014 (publication years 2009–2012; Web of Science) for %LOCAL UIC
- UIRC Scoreboard 2014 (publication years 2009–2012) for %DOMESTIC UIC
- U-Multi-rank 2014 (PATSTAT INCENTIM, Univ. Leuven; patent years 2002–2011) for %CO-PATENT
- U-Multi-rank 2014 (Web of Science; PATSTAT Univ. Leiden; patent and publication years 2002–2011; citing years 2002–2014) for %NPLR Share
- PATSTAT Univ. Leiden (patent and publication years 2002–2011; citing years 2002–2014) for %NPLR–HICI

They analyzed several universities with an attempt to develop a comprehensive index that consists of some combination of the seven indices in Table 8.1. One such index was obtained from the combination of the indices in the table, giving each of them an equal weight, labeling it as RIU—Equal weights index.

Statistical analysis could reduce or remove redundancies between the indices, where lower weights could be assigned to those that add little additional information. Such redundancies could be detected by applying statistical analysis to pairwise correlation coefficients between the selected metrics. Based on such analysis, different weights were assigned to the indices in Table 8.1, to define a single joint index based on non-equal weights using the following weights for the indices in Table 8.1:

%UIUC:	0.90
%MA UIC:	0.77
%Local UIC:	0.35
%Domestic—UIC:	0.60
%CO—Patent:	0.29
%NPLR:	0.74
%NPLR-HICI:	0.13

The index based on these weights is labeled U-I R&D Index.

Ranking of selected universities based on these indices was presented, indicating that the universities can vary in the intensity of university–industry relation for the various mechanisms. This suggests that there is a need for a pluralistic approach that is not based on a single measure.

The need for a composite index taking into account the various mechanisms of technology transfer and commercialization was highlighted by the European Commission Expert Group on Knowledge Transfer Indicators (Finne et al., 2011), outlining three types of indicators: Knowledge transfer through trained people (essentially similar to Knowledge Dissemination in Fig. 8.1), Institutional cooperation in R&D and other phases of innovation (essentially similar to Technology Transfer in Fig. 8.1), and Commercialization of research (essentially similar to Technology Commercialization in Fig. 8.1). A comprehensive metrics approach along such concepts was developed in the UK for evaluating the performance of universities, based on an extensive list of mechanisms of technology transfer and commercialization (Holi et al., 2008), such as:

Indices for Technology Transfer:

- CPD—Continued Professional Development
- Consulting (number of contracts, income)
- Collaborative research (number of contracts, income)
- Industrial research funding (number of contracts, income)

Indices for Technology Commercialization:

- IP (income, number of patents and licenses)
- Startups (number, turnover, investment)

These indices and more are part of the indices used in the UK to evaluate and provide public support to universities for their knowledge exchange strategy within the framework of the Higher Education Innovation Funding (HEIF). The data for such indices and evaluation is collected officially and presented by the Higher Education Statistics Agency (HESA). It is usually normalized to take into account the size of the university, and one of the common methods for normalization is to present the data per full-time equivalent of academic staff, FTE, namely each value is divided by the FTE value. The availability of such data is used to characterize each university, using a spider diagram.

This UK approach seems to be a sensible one as it provides a comprehensive quantification of the technology transfer of different universities and allows to resolve the differences in nature of such activities between the universities, identifying strengths and weaknesses. It also allows to promote the notion that the view of technology transfer should be a pluralistic one, with each university seeking the path where it has special added value. The application of this approach requires that all universities apply a similar code of data collection and presentation.

8.5 Case Study: Knowledge Transfer Processes in the Fields of Artificial Intelligence, Data Science, and Smart Robotics

Artificial Intelligence (AI) and Data Science (DS) are emerging fields whose significant influence on society is predicted to keep on growing. OECD experts claim that "AI is transforming societies and economies. It promises to generate productivity gains, improve well-being and help address global challenges, such as climate change, resource scarcity and health crises" (OECD, 2019). Cooperation between academia and industry is a significant factor in promoting AI and DS, as evidenced by a series of publications published by the Samuel Neaman Institute in 2018 and 2019 (Getz et al., 2018a,b, 2019).[1]

[1]In 2018, The Samuel Neaman Institute was commissioned by the National Council for Research and Development (MOLMOP) at the Ministry of Science and Technology to perform a comprehensive mapping of activities in the Israeli academy, industry and government sectors in artificial intelligence, data science and smart robotics and to explore the possibilities for promoting and developing these fields in Israel. For this purpose, the research group conducted interviews with nearly 90 specialists from around the Israeli ecosystem and surveyed employees from 160 companies. The research team published several different research reports, all can be found on the Neaman Institute website: https://www.neaman.org.il/Artificial-Intelligence-Data-Science-and-Smart-Robotics

Since Data plays a crucial part in the development of these fields, massive databases have always been considered valuable resources in search engines, social networks, and other companies. For many years, such companies invited academics to analyze their data. This helped power theoretical research in academia and realize predictive applications. It also created a symbiotic relationship between academia and industry, without which, the fields of artificial intelligence and data science would not have gotten as far as they did (Benson, 2018).

Recent research shows that the relationships between academia and industry in the fields of AI and DS are still evolving. Collaborative and participative relationships replacing the traditional technology donor-recipient relationship in these fields benefit both industry and academia: Industry benefit from getting access to state-of-the-art knowledge, creating innovative solutions for industrial problems, and improving competitiveness. Academia benefit from getting access to real data, educating students/researchers on real-world problems and applied research, and getting funds to support research activities (Khamis, 2015). There are also downsides to such relationships: Patel et al. (2019) suggested that the significant increase in the amount and depth of interactions and engagements between academia and industry presents increased complexities for universities to understand and manage the interaction and in particular the impact it has on the university culture and education mission.

There are many forms of academia–industry collaboration which are acceptable in universities, for example, receiving research funds from companies (such as Google and Microsoft) or a day per week consultancy work, done by researchers for companies. Temporary leave of absence which researchers take to work in industry for a given period can also be beneficial for universities because they often result in upgraded teaching skills. However, the challenge to academia comes when professors leave to join companies either en masse or individually.[2] This happens because demand for AI and DS experts in the industry has grown significantly and because the industry can offer researchers generous compensation packages together with distinct data sets and ample computational power. This can create some problems for universities, which are sometimes resolved through splitting researchers' time between industry and academia. (Time spent in both venues can vary from extreme 80/20 or 20/80 to an even 50/50 split (Peng, 2019)). However, such a split can lead to conflict of interests that needs to be mitigated through total separation between campus research and off-campus commercial activities. There are other, more synergetic approaches. For example: in 2001–2011, Intel established research labs in prominent computer science departments in American universities. The labs offered research funding and open intellectual property. Engineering resources and data sets provided opportunities to create powerful collaborations. The unavoidable influences on research agenda were monitored and properly disclosed (Etzioni, 2019). In recent years commercial research labs run

[2]See (Gan-El, 2018) and (Levy, 2017) for examples from Israel (HEB) and (Sample, 2017) and (Metz, 2019) for examples from the USA and the UK.

by Google Research, DeepMind, IBM Research, Nvidia, OpenAI, and others are becoming more significant. The distinction between industry and academy research groups is becoming blurred as the former extend their interest to cutting-edge research (Peng, 2019). Google, for example, had 107 papers accepted at the NeurIPS Conference in 2018, accounting for 10.5% of the total papers accepted by the conference (Microsoft Research, 2018).

In Israel, academy–industry collaboration has resulted in some extremely successful technologies, such as advanced driver assistance and warning systems technology used by Mobileye (acquired by Intel in 2017) and robots that learn and replicate tasks by observing humans, a technology which is used by the Technion's spinoff Deep Learning Robotics (DLR). The multidisciplinary nature of AI requires not only academia and industry working together but also clinicians and researchers working together in sharing their specific domain expertise to create clinically meaningful and translatable results (Lin, 2020). Examples of Israel's success stories involving AI and DS technologies in the life science domain are DayTwo, which uses customized nutrition recommendations technology developed at the Weizmann Institute of Science and Zebra Medical Vision which is based on the medical imaging insight and analysis platform developed by Mor Research Applications, the technology transfer company of Clalit Health Services (HMO). It is important to mention that the Israeli health system has gathered a large body of electronic data about patients, conditions, and treatments over the years on its interconnected EMR (Electronic Medical Records) systems. Up until recently the use of this data (in its anonymized form) was subjected to individual negotiation between the HMO or hospital which held the data and companies that wanted to use it. The use of such data usually involved a high fee (sometimes in equity). Recently representatives of industry and government (including Ministry of Health, HMOs, hospitals, the Innovation Authority, and others) started drafting guidelines for communication between public and commercial bodies on medical data that will regulate the subject, including financially, at the national level.

A current example of academia–industry collaboration in Israel is the new joint Intel-Technion research center dedicated to artificial intelligence technologies at the Technion, Israel Institute of Technology. As part of this collaboration, the company supports research projects of Technion faculty members engaged in computational learning and artificial intelligence together with Intel researchers. The research covers a variety of areas, including natural language processing, deep learning, and hardware optimization for different learning algorithms (Hattori, 2018). The Technion, like other Israeli universities, benefits from the industrial and academic experience of visiting professors from industry such as Dr. Kira Radinsky, chairman and CTO of Diagnostic Robotics (formerly chief scientist and the director of data science of eBay) who teaches deep learning and natural language processing and also Mentor students for graduate degrees. Another example of Israeli academia–industry collaboration is the Check Point Institute for Information Security (CPIIS).[3] The institute is located at the Tel Aviv University School of Computer Science, and its activities include supporting selected research projects, providing post-doctoral fellowships, providing stipends for graduate students, providing a laboratory environment for experimental research, and organizing workshops and symposia. The CBG[4] (Cyber@Ben-Gurion University of the Negev) is an umbrella organization at Ben Gurion University, being home to various cybersecurity, big data analytics and AI applied research activities. It is a salient academia–industry–government collaboration with the Israeli National Cyber Bureau, the Israeli Police, and Telekom Innovation Labs as partners.

8.6 Policy Implications: Technology Transfer Versus Technology Commercialization

8.6.1 Income Generation Versus Technology Diffusion

Optimization of "technology commercialization" policies is often the main driver for TTO's/TLO's existence. It is largely driven by the attempt to maximize revenues for the university and with this goal in mind, IP protection policies are being developed. However, the data presented suggest that the income received is relatively small. Merrill and Mazza (2011) reported that the average "rate of return" on funded research is about 4.1% and the median is 0.9%.

More than that, estimates of the net income from commercialization, after considering the expenses involved, such as staff of TTO and patent expenses, suggest that out of 155 TTOs reporting to AUTM, 130 did not break even and were at a loss; it is estimated that over the last 20 years 87% of the universities did not break even (Valdivia, 2013). This is further echoed by Love (2014), based on a survey which concluded a negative rate of return (e.g., loss of about 3%), and similar trends reported by Thursby and Thursby (2007) based on surveys.

These gloomy trends seem to have remained approximately constant over most of the last two decades.

Thursby and Thursby (2007) discussed several issues in view of the limited or negative financial gains by licensing and based their analysis on responses to surveys they have taken. Most important was the input of the university stakeholders with regards to the goals of technology transfer: Administration and TTO/TLO officials see it as highly important while faculty take the position that financial gains is not the only goal, as seen from the importance of indicators to success. The opposite is the response to the issue of sponsored research funds: faculty see it as highly important while administration and TTO/TLO officials place it as mildly important.

[3] http://cpiis.cs.tau.ac.il/

[4] https://cyber.bgu.ac.il/

In the consideration of faculty perception, there is a need to consider the variability of the faculty personality and attitude. Lavie (2019) suggested to approach the faculty taking into account three different profiles: (i) faculty who have the entrepreneurial intentions as well as the skills and can proceed in realizing the potential of their invention on their own, (ii) faculty who have no interest in entrepreneurial activities to develop further their inventions and prefer to let the organization proceed with it without their intervention, (iii) faculty who have entrepreneurial aspirations but do not have entrepreneurial skills, who want to lead the application of their inventions in spite of their lack of the capabilities needed. The policies for the first and second groups should be quite different, while the third group, is the most problematic. Consideration of these differences suggests that flexible policies need to be developed, and the TTO/TLO should be autonomous in implementing them, considering the profiles of the faculty members.

In the assessment of technology diffusion, attention should be given to the possible negative impact of policies based on maximizing income which leads to stringent IP protection considerations. Issues of IP protection and commercial interests have often been cited as impediments in academy–industry negotiations in research contracts (e.g., Deloitte, 2019), which result in a disappointing level of cooperation, as might be observed in the data in Fig. 8.6. It has been suggested to look more into generic standard contract practices, but this is not always an option considering the differences in the nature of technologies, industries, and markets (e.g., Deloitte, 2019).

8.6.2 New Policies and TTO/TLO's Missions

New policies and missions for TTO/TLO require reconsideration of strategies of universities with respect to maximizing their income. Increasing the probability for a blockbuster might be achieved by several means such as redirecting and focusing the research into the most attractive fields for the emergence of blockbusters and motivating faculty by providing special incentives for promotion. These, however, will probably be met with strong internal resistance as well as the risk of jeopardizing other university goals.

In view of such insights, new ideas about strategies have been emerging. Valdivia (2013) discussed alternative strategies to manage IP and proposed several policy recommendations:

- Government should provide more funding to Small Business Technology Transfer (TSTTR) programs, designating funds specifically for university startups.
- Congress should authorize a patent use exemption for non-profit research organizations for exclusive experimental use. Also, enable federal agencies to use march-in rights under the Bayh–Dole Act to extend nonexclusive licenses for research tool patents that have been subjected to pricing excess.
- Create an equity rule for the distribution of funds among universities.

Additional ideas and review of several models of the mode of operation of technology transfer units have been reported by Allen and O'Shea (2014):

Gateway approach: intended to minimize obstacles for commercialization by joining the offices dealing with research, contracts, technology transfer, relations with industry, and support for entrepreneurship.

Centric approach: The university develops long-term alliance with experts in commercialization and IP to get into the market attractive ideas.

Academic Entrepreneurship Model: The office of technology transfer is actively participating in setting relations between faculty members and venture capital firms (VCs) and allows them to advance in the entrepreneurship process. The university gets a small share and the TTO is not involved in running the process. The emphasis is on getting a process going and making an impact on the community.

Easy Access IP Model: The model was developed in Europe and it provides the IP freely. It does not allow for income to the university but enables a great deal of inventions to reach society. As the emphasis is on impact, the university hopes to generate sources for financial support of research with the growth of companies based on this IP.

8.6.3 IP Protection Policies and the Bayh–Dole Act

In view of this situation, there is considerable debate whether there is a proper balance in university policies and mode of action of TTO/TLO, between technology commercialization and technology transfer. This has been echoed in several reviews of the developments following the Bayh–Dole Act of 1980, questioning whether universities have overemphasized technology commercialization which takes place largely by the "linear model," at the expense of technology transfer, which is more likely to promote interdisciplinary activities made up by groups of scientists from the academia and industry working together.

Sampat (2006) stated that the purpose of the Bayh–Dole Act was not to provide revenues to the universities or change the nature of the research from basic to entrepreneurial and applied, but rather to encourage technology transfer to the industry and private sector, which could be developed from basic-academic research that was not commercially oriented. Since the technology transfer from university is taking place by several modes, in addition to patenting and licensing, it is essential to evaluate the effect of the Bayh–Dole Act by considering the whole array of mechanisms. The issue is whether the changes with regards to patenting affected the traditional mode of knowledge transfer such as publications, conferences, and informal channels. There is the question of whether universities are patenting "science" rather than embryonic technologies. The societal costs and benefits of the Bayh–Dole Act depend less on whether university research is patented or not, but more on how it is licensed, which is the policy issue that needs to be addressed.

From a societal point of view, one would like to patent public-funded university research output only in the case that without it the research output would not be effectively utilized. Also, exclusive licensing should be granted only when a nonexclusive one will not enable commercialization.

It is, thus, best if universities take at their initiative steps for managing patenting with the perspective of the public interest rather than their own financial interest. Consideration for changing the current model of IP ownership which follows the Bayh–Dole Act was suggested by Kenney and Patton (2009).

Some insight on the impact of IP protection policy might be gained from a study by Valentin and Jensen (2007). They compared technology transfer in Denmark, where a law like the Bayh–Dole Act was enacted (Danish Law on University Patenting—LUP), to Sweden, where the traditional European policy of academic researcher ownership of IP was maintained. It was concluded that the LUP resulted in a moderate increase of inventions channeled through the university-owned patent system, but the larger part of the inventive potential of the academia, previously mobilized into company-owned patents, seems to have been compromised as a result of the law. A likely explanation is that exploratory research, which is usually a target in university–industry joint projects, especially in biotech firms, matches poorly with LUP IP requirements: The pre-LUP system, allocating IP rights to the industrial partner in return for research funding and publication rights to the academic researcher, may have offered more effective industrial contracting for research. It is concluded, however, that LUP is not uniform in its effect on joint university–industry research: it will operate better for joint R&D issues closer to commercial technologies, i.e., exploitive research, but less well for explorative research.

8.7 Concluding Remarks

The spirit of the concluding remarks echoes quite well with a statement made by Lita Nelson, the previous director of MIT TLO, in a recent interview (Engell, 2016):

> *It's already changing with an emphasis on entrepreneurship. The tech transfer offices have recognized that except for a few pharmaceuticals—and very few of those, that have been brought along by hospital funds to the point where the big pharma wants it—on the whole what comes out patented from university research is too risky and too early for knocking on the door of established companies.*
>
> *Any university that counts on its tech transfer to make a significant change in its finances is statistically going to be in trouble.*
>
> *So, the universities have to start figuring out how do I ripen the technology to the point where it enters the big company stream of commerce.*

Based on the survey findings, insights, and discussions presented here, a need emerges for reevaluating and revisiting university policies with regards to its third mission. Such policies should be set to guide the activities of the TTOs and TLOs, which need to balance between technology commercialization, which is more linear in nature, and technology transfer with industry, which is more holistic, interactive, and entrepreneurial in nature.

Goals should be set for the academia's contributions to the national economy and societal needs, and IP protection policies should be adjusted.

Greater emphasis on technology transfer and more intimate cooperation with industry may result in an increase in research funding as well as in improved level and significance of research. More than that, such policies are more likely to be met by support of the academic faculty, and they should be an inherent part of the development of entrepreneurial activities in universities, which include education that is suitable to the needs of the industry and society, as well as more significant and effective research.

It is recommended that the achievements of the universities regarding the third mission should be quantified and ranked on the national and international levels. They should be based on multiple indices to reflect various modes of achieving such goals, in view of the range of mechanisms of university–industry interactions.

Also, there is a need to consider the promotion of the academic staff, their achievements, and contributions with regards to the third mission.

Nowadays, we are in the era of the fourth Industrial Revolution, Schwab (2017), which challenges the academia to enter and contribute to new areas in advanced research and advanced education in order to remain relevant during this revolution. The education syllabus and teaching methodologies should be modified and updated to meet the challenges and opportunities of this revolution. The research agenda should include these new areas of interest. But, more than that, the interactions between academia, industry, and society should be substantially more active, holistic, and entrepreneurial in nature.

This calls for a comprehensive approach from all the stakeholders, as outlined concisely below:

Academia

- *Mechanisms*: move from commercialization to transfer of technology
- *Finances*: move from royalties' income to industrial research funding
- *TTO/TLO*: entrepreneurial approach of nurturing intimate industrial relations
- *IP policies*: relaxing, with view of long-term industrial support and donations

Industry

- *IP policies*: flexibility for publishing in return for IP rights
- *Nature of research*: support explorative research, not just exploitive/applied research

Government

- *Policies*: develop policies with long-term objective of having a sustainable ecosystem
- *Incentives*: set criteria for incentives to universities for achieving third mission goals, based on multiple indices

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Chapter 9
Models for Planning and Budgeting in Higher Education

Zilla Sinuany-Stern

Abstract The budget of an organization reflects its plan in monetary terms over a given period—usually for a year. This chapter is devoted to planning and budgeting in higher education (HE). We present various budgeting procedures, such as incremental budgeting, along with costing methods in HE institutions (HEIs). A variety of optimization models with budget constraints and bounds on the allocations to organizational units are given, where the bounds are a result of the planning process and past budgets. We present linear and nonlinear objective functions (quadratic), with and without constraints, intertwined with a simulation scheme in an HEI. The optimization models are presented in a single and multilevel hierarchy, and over time. Moreover, several aggregative long-run financial models are presented. We conclude that the quadratic model fits HE better than the linear model since it provides allocations around the midpoints of the upper and lower bounds of the allocations rather than the extreme linear model's allocation. We determine that the quadratic model procedure is preferred, as its optimal solution is intuitive and does not require mathematical formulation and skills. Moreover, the relationship between the mathematical models and known budgeting procedures are analyzed, and we conclude that the optimization/simulation scheme described here results in a combination of several budgeting procedures—as actually happens in practice.

Keywords Planning · Budgeting · Higher education · Simulation · Optimization · Hierarchical · Linear · Quadratic

Z. Sinuany-Stern (✉)
Department of Industrial Engineering & Management, Ben Gurion University of the Negev, Beer Sheva, Israel
e-mail: zilla@bgu.ac.il

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9.1 Introduction

The budget reflects the plan of an institution in monetary terms over a given period (Lasher & Sullivan, 2004). It has two parts: the operational budget, usually for 1 year, and the capital budget, often for more than 1 year. Budgeting is the process of identifying, gathering, summarizing, and communicating financial and nonfinancial information about an organization's future activities. The budgeting process provides managers with the opportunity to match organizational goals with the resources necessary to accomplish those goals. Sometimes, prior to the budgeting process, strategic planning is performed, where the long-term goals are established (usually a 5- to 10-year period) that form the basis for preparing the annual operating and capital budgets.

This chapter is devoted to planning and budgeting in higher education (HE). Historically, HE has been defined as a nonprofit organization. The leading HE institutions (HEIs) are comprehensive universities, which include teaching and research facilities, typically awarding Bachelor's, Master's, and Doctorate degrees in a variety of disciplines and professions. The main production workers of an HEI are full-time (FT) tenured academic faculty, whose activities' quantity and quality determine the level and prestige of the HEI. Besides teaching, FT faculty must perform research and must receive grants and other resources to enhance their research. Some contribution to the community is also expected of tenured faculty. This multitasking, mainly between teaching and research, with vague borders and fuzzy requirements, creates tension among faculty and between HEIs, and even competition. International rankings of HEIs and the h-index of researchers are its extreme symbols. All these elements determine the difference between secondary and postsecondary education.

Successful modern universities strive to have a wide national and international impact on society and economics. For example, on its website, the University of California, Berkeley, which is ranked among the top universities in the world, states as part of its mission:

> *...Berkeley also contributes to the economic welfare of the state and world, building industries and commercializing technologies whose impact is felt around the world. Tens of thousands of companies have been founded by Berkeley students and professors, creating well over a million jobs, and generating several hundred billion dollars in economic activity. Berkeley is also a crucible for the talented workforce that drives California's innovation economy: offering a first-rate education to more undergraduates than Stanford, USC, and CalTech combined, Berkeley and its graduates truly power Silicon Valley...* (Berkeley, 2020)

Although public HEIs have been defined as nonprofit organizations, as the altruistic statement above reflects, we can see that even in its mission a state university such as Berkeley is proud to include for-profit goals. Moreover, the above mission statement has a marketing flavor. Slaughter and Leslie (1997) call it: *academic capitalism*, and the *entrepreneurial university*. Moreover, Etzkowitz (2001) declares that the rise of *entrepreneurial science* in HEIs is proof that we are in the midst of the *second academic revolution*, the first academic revolution being the creation of mass HE.

Bogomolova et al. (2017, 2018) claim that, even in Russia, universities are involved with industry in their budgeting; moreover, they prove that total university R&D is positively correlated with the main macroeconomic indicators in both Russia and the USA.

Smith (2019) claims that a university is a business; moreover, university budgeting terminology is the same as in business, providing an overall description of all aspects of the budgeting process. The goods and services of a university are instruction, research, dormitories, cafeterias, and other services. The workers of the university include academic, administrative, and technical staff—all of whom receive salaries from the university. The university constructs buildings for classrooms, offices, libraries, sport facilities, etc. It uses marketing to attract students and to improve its rating. Moreover, universities are involved in export/import, namely, in the form of international students and researchers. To finance all these needs, a university acquires resources from student fees, government allocations, donors, and graduates. These various constituencies expect transparency regarding resource allocation and accountability in reference to outcomes and achievements. The annual budget is the overall summary of all these inputs and outputs.

Appendix 1 presents an annotated literature review of over 40 publications devoted to planning and budgeting in HE by type of model used, area of application, HE level (department, university, state, etc.), and country of application. Most of the articles include mathematical models for planning and budgeting including optimization, simulation, or forecasting. Some publications are devoted to known budgeting procedures such as ZBB and PPBS (see Sect. 9.2). Most applications were applied at the "university level," with 18 in the USA.

In this chapter, we present a general scheme for an optimization and simulation model for planning and budgeting in HE (Sinuany-Stern, 1984b). Planning comes before budgeting in various systems and subsystems of HE, utilizing various operations research and management science models. Various budgeting procedures (such as incremental budget and allocation formulas) and optimization models with budget constraints and bounds on the allocations to organizational units are given, where the bounds are a result of the planning process with a linear objective function (ibid.) versus a quadratic objective function (Sinuany-Stern, 2014). Moreover, several aggregative long-run models are presented (Sinuany-Stern, 1983a). We show the relationship between the mathematical optimization models and known budgeting procedures.

The strength of this work is in combining a variety of mathematical models with known budgeting procedure models, relating to various aspects of planning and budgeting at different levels of HE, and over time.

This chapter is organized as follows: Sect. 9.2 presents the main types of budgeting systems used in HE. Section 9.3 lists expenses and income typical for HEIs and methods to estimate these and their projections. In case there is a deficit, a simulation/optimization budgeting scheme is presented. Various types of optimization models for budget allocation are given in Sect. 9.4, when resources are scarce. Section 9.5 presents aggregated university long-run budget planning models under various assumptions, and Sect. 9.6 concludes the chapter.

9.2 Types of Budgeting Systems

There are five main budgeting methods relevant to HE: Incremental, ZBB, PPBS, formula budgeting, and responsibility-centered budgeting.

9.2.1 Incremental Budgeting (IB)

Incremental budgeting (IB) is the oldest and most widely used budgeting method. It is often based on the most recent budget by adjusting each item in the new budget by a certain percentage from its historical value, without relating to its priorities or outcomes. The imbedded assumption is that costs and allocations will be incremental, as in the past. IB is often used by HEIs for its simplicity (Barr & McClellan, 2018). However, it does not account for major changes in plans; thus, often it is combined with other budgeting approaches as needed; namely, certain parts of the budget are incremental (such as for existing departments), while others are not incremental (such as for new departments or new projects).

9.2.2 Zero-Based Budgeting (ZBB)

Zero-based budgeting (ZBB) is the opposite of IB. It allocates the budget based on program efficiency and necessity, rather than on budget history. ZBB reviews every program and expenditure at the beginning of each budget period and justifies each line item in order to receive more funding. The new budget always starts from a zero value for each line item. It requires considerable work and time to justify and compute how much to allocate for each line item—if at all. Moreover, implementing ZBB is a long and costly procedure in which internal conflicts may arise within the institution (Goldstein, 2012), and in practice, it is impossible to implement in its pure form (Barr & McClellan, 2018, p. 85). Ekanem (2014) reports on implementing ZBB in a Nigerian university.

9.2.3 Planning–Programming–Budgeting System (PPBS)

Budget planning models have been used in HE since the 1960s (Terrey, 1968). Weathersby and Balderston (1972) reported about the use of PPBS (Planning–Programming–Budgeting System) for budget planning in various parts of the USA and other countries. For example, during 1966–1971, PPBS was used by the University of California for budget planning (Balderston & Weathersby, 1972), and in 2009, Gibson (2009) reported on the use of PPBS in HE. As a top-down budgeting method, it fits the hierarchical HEI budget. The main attributes of this system are that it relates means to ends (outputs), qualitative dimensions are considered, activities are aggregated to programs, and various alternatives are evaluated quantitatively and over time. Thus, PPBS helps in decision-making. Its disadvantages are that the notion of a program is vague in HEIs (e.g., department), the top-down and bottom-up processes are cumbersome and require strong centralized leadership, outcomes of programs are not always easily measured, and a special management information system needs to be built to implement the system. Barr and McClellan (2018, p. 214) stated that PPBS is a quite complex budgeting model for HEIs.

9.2.4 Formula Budgeting

The future of a program is calculated by the relationship between its costs and program activity level—often via historical data or a tariff developed per unit of activity. For example, the state planning and budgeting committee can develop sets of formulas for HEIs in that state for teaching per student by type of institution and by type of department. For research, this can be done by the number of papers published and number of citations, by type of grant and its amount, and specific allocations for special projects (e.g., in the case of Israel, see Frank, 2012). This method is intuitive after the tariff is agreed upon. It has some equitable properties that are often violated by dividing institutions into two or more types due to seniority or other criteria. Formula budgeting is easy, and has fewer conflicts, especially after a formula has been agreed upon for some years. It seems fairer and more straightforward (Brinkman, 1984; Fonte, 1987). However, drastic changes in enrollment may cause problems, especially when a formula is enrollment based (Thomas, 1999). The formula may change to include reservations of various constituencies over time, till it becomes so complicated that its fairness is questioned again. Formula budgeting is often used at the state level to allocate budgets to HEIs (Barr & McClellan, 2018).

9.2.5 Responsibility-Centered Budgeting (RCB)

RCB means, in its purest form, that each academic unit (department, school, college) is responsible for all the costs it produces and receives all the revenues it generates; namely, academic departments and support units are the cost centers for fiscal purposes and are expected to be self-supporting (Zierdt, 2009). Other terms for RCB are value-centered management, cost-centered budgeting, profit-centered budgeting, and revenue responsibility budgeting (Barr & McClellan, 2018). RCB has also been widely used in business. Those who understand their operations best, such as department and school heads, should be given greater budgetary authority and responsibility (Dubeck, 1997). Deering (2015) examined the implications of RCB for the internal structure and strategic management of North American universities. Although it seems that since the 1980s, universities have gradually moved from centralized incremental budgeting to decentralized RCB (Whalen, 1991), in practice, this is not so, Deering and Lang (2017) show that RCB is never fully deployed. To resolve this anomaly, Myers (2019) built a moral-hazard mathematical model with an asymmetric information situation, in which the top administration does not have full information about the efforts and revenues of a specific faculty member. He proved that only a pure RCB is optimal as it maximizes the HEI's revenue and solves the incentive problem of faculty efforts. However, if the faculty is risk-averse, then the pure RCB is not optimal, and as the revenue becomes uncertain, the RCB becomes less pure. In practice, in a large prestigious research HEI with a large endowment fund, there is less uncertainty of the revenues; thus, such universities use a purer RCB in comparison to small teaching colleges (ibid.).

These five budgeting procedures are the main methods applied in HEIs. However, there are many more budgeting methods and variations such as initiative-based budgeting and performance-based budgeting (Goldstein, 2012), activity-based budgeting (Kenno & Sainty, 2017), the executive budget model (completely centralized), and performance budget (e.g., the number of students and number of credit hours; Gibson, 2009). In practice, the budget may often be a combination of two or more methods. For example, most budget items may be based on incremental budgeting, whereas a research budget may be based on responsibility-centered budgeting.

Soares et al. (2016) pointed at the networked organization as an ideal structure that links various departments and functions within an HEI through sets of expectations while providing benefits to all partners based on a unified information system that allows various alternatives of costs and outcomes and their consequences to be analyzed. The orchestrators of a network budgeting process could be the institutional research office, which already performs in a similar manner. Such a network is not necessarily hierarchical. The existing shared governance structure could be the basis for the network as a participative form of management. The next section provides a listing of expenses and income in HEIs, highlighting the special structure of an HE budget.

9.3 Expenses and Income in HEI Budgets—Estimation/Simulation

Budget allocation is a product of the planning process. We make a clear distinction between resource requirements and resource allocation. Budget allocation is the actual annual amount committed to each component of the organization to be applied toward its needs, taking into consideration a given limited budget that meets its requirements either fully or partially. In budgeting terminology, resource requirements are usually equivalent to budget requests, whereas resource allocation is equivalent to the approved budget. This section is based mostly on Sinuany-Stern (1983b) and Sinuany-Stern (1984a).

HE is differing in relation to other public sector institutions, even in relation to secondary education, in its income and expenses. In addition to the teaching function, faculty members are expected to perform independent research. Furthermore, academic freedom is very specific to HE. Often faculty must apply to internal, but mostly to external, sources to receive funds for their research, to support their laboratories, equipment, materials, along with technical manpower and assistants. Some grants are limited to certain areas of research, whereas others are not, but require the submission of detailed proposals from researchers that are carefully reviewed. Some grants come from public sources (such as the state) or private organizations (such as independent companies). Sometimes, there is a contract between the researcher and a company regarding patent rights, etc., and often the HEI charges overhead (e.g., 15% of the grant), with support given by the HEI to the research. There is great flexibility among various types of HEIs regarding the extent of research versus teaching, covering the spectrum of zero research (in most community colleges) to almost 100% research (in some research institutes that have only research students). There are large differences regarding the average grant amount per faculty member even within the same department, and among departments. For example, a researcher in mathematics or literature usually does not need heavy equipment and materials like a researcher in biology or chemistry. The researcher is usually a full-time faculty member in a tenure track and is free to apply or find sources for research. For full-time faculty, the portion of time to be devoted to teaching in relation to research and administrative duties is vague, and varies among HEIs, within institutions, and even within a specific department.

To prepare a budget that reflects the coming year's plan of an HEI, there is a need to know the current and past year's budgets and how well they match the current and past year's plans (Barr & McClellan, 2018). Without such detailed information and a good supporting educational cost accounting information system at the desired level connecting between *costs* and *activities* (performance), be it in a program, a department, or a school, sophisticated cost accounting such as ABC (activity-based costs) is not viable in HE (Massy, 1996; Soares et al., 2016). Even so, Soares et al. (2016) report that community colleges (CCs) do use ABC successfully. Perhaps this success stems from the fact that CC faculty focus mainly on teaching, while university faculty focus on submitting research proposals for funding, with great variability among them. They also change over time as opportunities may emerge unexpectedly. It is ideal to have the equivalent of MRP (material requirement planning) for HE academic activities as is done in industrial engineering. However, this is impossible in HE due to the fuzziness of inputs and outputs, and their costs. Thus, it is hard to pinpoint the marginal costs of university activities as Massy (2017) suggests is the ideal case.

9.3.1 Budget Expense Structure

As shown in Fig. 9.1, the student enrollment forecast is the basis of budget generation in HE (Sinuany-Stern, 1983b, 1984a; Trusheim & Rylee, 2011). The number of faculty needed is based on enrollment and the full-time/part-time mix policy of the HEI, which determine the number of each type of faculty since the salary of full-time tenure track faculty is much higher than part-time faculty. Many assumptions in planning and aspirations are imbedded in predicting the various expenditures in each HEI.

The main types of expenses which comprise the total expenditures, shown in Fig. 9.1, are:

1. Instructional expenditures: faculty compensation (full-time and part-time, depends on the mix and variability of salaries by discipline—mainly in private institutions), other instructional compensation, external vendors, and e-learning expenses.
2. Academic support expenditures: other employees' compensation needed to support students and faculty, labs, equipment, computer hardware and software, internet access and technical support for academic and administrative purposes, marketing expenses to recruit students locally and internationally, library expenditures, deans' office expenditures, and departments' office expenditures.
3. Institutional support expenditures: utilities, supplies, and materials, depreciation, amortization, interest, and other operating costs.
4. Students' services expenditures: registration, counseling, academic development, health services, financial aid, support for needy students, job placement service for graduates, and preparation for the job market.
5. Public services expenditures: museums, sport facilities, lifelong learning, shops, and cultural activities.
6. Overhead: physical plant operations expenditures, which depend on gross square meters by type of facility, computer services, utilities, property taxes, financial services, human resources, central administration, materials purchasing and management, fundraising, and marketing.
7. Research expenditures: long-run projects, grants, and contracts.

Another approach, presented by Goldstein (2012), is to display the expenses in a matrix form showing the functional categories (e.g., instruction, research, public services, etc.) by type of expenses (e.g., personnel compensation, services and supplies, and utilities). In fact, the main expense in the budget is human resources, especially full-time and tenure track. Toutkoushian and Danielson (2002) use the following performance measure of academic faculty: 1. Inputs: student headcounts, percentage from under-represented racial/ethnic groups, average SAT/ACT scores of freshmen, high school GPA or class rank of freshmen, percentage of applicants who are admitted, percentage of admitted students who enroll, and average faculty salaries. 2. Production process: expenditures per student, student-to-faculty ratio, credit hours per faculty member, percentage of courses/students taught by tenure-

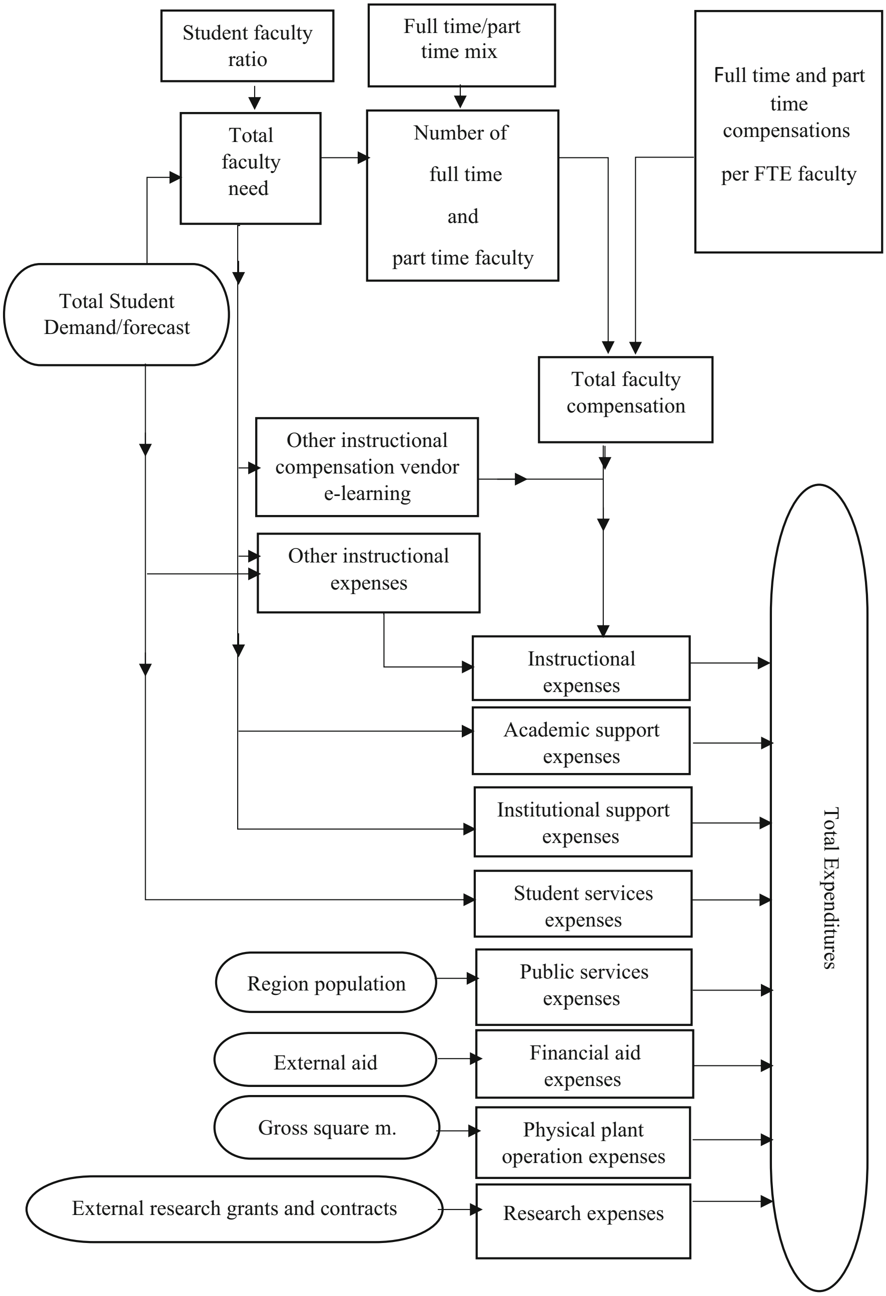

Fig. 9.1 Higher education institution's total expenditures

track faculty, expenditures per student by major category, revenues per student by major category, and level of deferred maintenance. 3. Outputs: number of faculty publications and number of degrees awarded. 4. Outcomes: reputational rankings (e.g., university ranking by USNWR), percentage of alumni who have donated to the institution, retention rates (from freshmen to sophomore, etc.), graduation rates (4, 5, and/or 6 years), the average time to degree, research grant dollars received, and student satisfaction (from surveys). A more detailed breakdown is possible depending on the needs of the HEI. Other examples for breakdowns for type of expenses and their subcomponents are given by Hanover (2010).

Figure 9.1 gives a simple outline of an HEI's expenditures. For more details and an application of cost estimation of various specific types of expenses such as the sum of a fixed cost and a variable cost multiplied by the amount of different variables, see details in Sinuany-Stern (1984a). For example, the total cost of academic support is a fixed cost, plus the variable cost per faculty for academic support multiplied by the number of faculty. It is possible to identify from past academic detailed expenditures those which are fixed regardless of faculty number, and those that are dependent on the number of faculty to estimate the fixed and variable costs (ibid) Fig. 9.1 shows the functional relations for the main expenditures of an HEI. Another way is to use linear regression models to estimate the intercept (fixed costs) from the data and the slope (variable cost per unit, e.g., academic department). For example, Weathersby (1967) used linear regression to estimate fixed and variable costs per student, based on the actual past expenses of departments.

9.3.2 HEI Budget Income

There are several types of main income in HEIs, most of which are specific to them:

1. Tuition—differentiate between local students and international students, and by degree.
2. Student fees such as room and board.
3. Financial aid (from external sources).
4. State and government support.
5. Donations and gifts from alumni, organizations, etc.
6. Investment income (e.g., from past endowment funds).
7. Grants from national and international sources.
8. Sponsored research from government and other sources.
9. Contracts with business and industry from patents, other royalties, auxiliary enterprises, incubators, etc.
10. Educational activities and auxiliaries such as services of academic departments, conferences, museums, sport facilities, lifelong learning, shops, and cultural activities.

9.3.3 Determining Versus Predicting in Budget Planning

The HEI must decide how much control its administration has on the plan, and how much uncertainty exists. For example, enrollment projection for a top-ranking university with a very high enrollment of outstanding students allows that university to determine the number of students according to its planned capacity, which reduces risk. However, most universities do not have such full control of the number of students. They can increase their control on enrollment by investing in marketing (advertisements, etc.), while passive HEIs may use various methods to forecast enrollment. Sinuany-Stern (forthcoming-a) presents many forecasting methods such as the ratio method, time-series, regression, and data mining.

Linking enrollment predictions and tuition income models is common, as applied by Trusheim and Rylee (2011) for the University of Delaware. The enrollment matrix is constructed from past enrollment data by semester over several years by type of entering students (freshman, transfer, readmitted, and continuing). The forecasting model is based on a cohort survival method, with prediction based on average historical percentages for each group, where the head of the university can dictate a total target. The tuition model is integrated, where the enrollment breakdown of the full-time/part-time ratio by the resident/nonresident ratio is used to calculate the desired income from tuition based on full-time tuition versus part-time tuition, and resident tuition versus the higher nonresident tuition. The desired ratios are transmitted to the admissions office to consider in their admitting process. This model is a good example of how the policy of HEIs can affect enrollment and the income from tuition.

Regarding the forecast of the number of faculty, there is more control since the tenure track faculty is determined by the administration via changing the student–faculty ratio by adjusting class size in the worst case. The full-time/part-time faculty ratio is another parameter the administration can use to control total expenditures. For example, De La Torre et al. (2016) suggest a mixed-integer linear programming (MILP) model for long-run planning of academic staff in a public university: its size by department and by type of categories, and the cost of each type. The objective is to minimize total academic staff costs, and different scenarios are tested. The various costs and expenses and incomes can be predicted similarly. For example, Sect. 9.5 provides seven types of models for estimating the total expenses and total income of an HEI over time (see details in Table 9.3) such as linear growth (a constant amount) and exponential growth (a constant percentage).

According to state-level budgeting, often the number of students is controlled by the state, and the graduation rate is also a measure used to determine a state's allocation to an HEI. Often the cost per student varies significantly among disciplines, as in the Israeli case [to this date by the Council for Higher Education (CHE; Frank, 2012)], although the allocation for research is based on the achievements of each university by examining two criteria: publications by their impact factor and the number of competitive grants secured by the faculty. Thus, only seven universities are entitled to full research allocations, while over 50 state HEIs are not (ibid.).

Other allocations for enhancing specific minority groups and special activities are also allocated, e.g., annual allocations by the Israel Science Foundation (ISF), which awards grants to individual researchers based on their proposals, which are reviewed by international reviewers. Another example is a program for improving the quality of teaching, which I championed as the chair of the Israeli Quality Assurance Committee (when I was a member of CHE during 2012–2017). Consequently, HEIs in Israel are allocating some funding to enhance teaching quality based on several criteria. This is a case of spending a small amount of money to achieve significant improvement in teacher and student satisfaction.

On the HEI level, to calculate the cost per student by academic department, it is necessary to consider the Induced Course Load Matrix (ICLM), which provides the number of contact hours each department provides to each of the other departments (Sinuany-Stern et al., 1994, p. 553). Using this approach to calculate the average cost per student by the department at a specific university, the decision was made to close one department. However, using cost per student as a main criterion can be misleading, as is shown in this case. When using data envelopment analysis (DEA) in which several academic monetary and non-monetary criteria are used (e.g., number of publications and grant money received by faculty), the department was found to be efficient and, indeed, eventually that department was reopened (ibid.). The cost per student was used to measure departmental efficiency in relation to DEA, which considers multiple inputs and multiple outputs of academic departments such as research outputs (ibid. and Johnes et al., 2017). As shown by Sinuany-Stern (forthcoming-b), DEA is one of the OR methods often used in HE, mainly for measuring efficiency, benchmark analysis, and pointing at improvements needed (see Sinuany-Stern & Hirsh, forthcoming).

In some cases, the importance of marginal costs can be crucial. For example, while provost of Ariel University, I was aware that the Physical Therapy (PT) department had a very high demand. However, the department head wanted to limit student numbers since there was a shortage of professors with PhDs in the field. When the issue was brought to me, I found that the largest possible class in the department was 50 students. Moreover, the marginal cost was extremely high because of the laboratory equipment and field training requirements—even with state support, this cost was higher than the marginal income per student. Thus, we were losing money on each student. As a result, I decided not to increase freshmen enrollment beyond 50 in that department. I convinced the Board that such restrictions would cause high demand which will cause some spillover of good students to similar departments (such as health management) with low marginal cost, and create prestige for the new department and for the new university. In the end, we were able to meet the planned enrollment by accepting more students in departments with lower marginal costs such as Health Management. In this case, the difference between the marginal costs was so obvious, that there was no need to perform exact calculations since there are no expensive training requirements in the related departments.

Regarding the investment in a large research facility, Philbin and Mallo (2016) adapted the known Management Successful Programs (MSPs®) to support the strategic decision of investing in a research facility that can serve various additional departments and external purposes that may put the organization ahead in a specific scientific area. This analysis is done before such items enter the budgeting process. Special projects that span several years often are not included in the operational budget, such as facilities building, as they are part of the development (capital) budget. In this case, due to their risks and other expected expenses and income over time, the algorithms for generating the discrete efficient frontier to a capital budgeting problem can be used (Rosenblatt & Sinuany-Stern, 1989), where the projects are ordered according to their ratio of risk and expected rate of return, with the ranges of the risk-averse weight (the weight ranging from 0 to 1).

9.3.4 Incentives for Maximal Performance in HE Via Budgeting

Budgeting formulas may include incentives for encouraging specific performance in HE. For example, the state may wish for public HEIs to increase the number of students and the graduation rate. Moreover, for a comprehensive public university, the state expects HEIs to increase their research output in number and quality. Thus, the budgeting formula would be designed to foster these objectives by accounting for an increase in enrollment and students' success rate of graduation, and for more publications in high impact factor journals (as is the case of the Israeli formula to this day, as shown by Frank, 2012). Another example at the state level is given by Toutkoushian and Shafiq (2010), showing a model that proves that need-based financial aid to students is more beneficial than giving state appropriation to the college. However, solving one problem sometimes causes another, in this case, the brain drain problem, where students who can get state aid may go to study in another state. Thus, they suggest conditioning financial aid to students who attend an in-state HEI (ibid.). Another example is the US federal government that gives loans and direct grants to needy students.

Often a survey is needed to learn about some practices in HEIs for planning purposes, for example, Henry-Moss et al. (2019) explored the planning of space for lactation in community colleges in the USA and their funding. They used a survey, whose findings were used to plan better facilities to accommodate nursing mothers on campus. Such facilities are incentives for such women to return to school.

Among the incentives for research and teaching quantity and quality that I initiated as the Provost of Ariel University (2000–2008) was a program for encouraging faculty to excel in teaching and research. As reported by Davidovitch et al. (2016) and Davidovitch and Sinuany-Stern (2014), 60% of the faculty at the university were awarded an increase of up to 20% of their salary based on their teaching and research performance. There was a list of criteria used and points given per criterion (e.g., number of publications, grants, the average number of students in courses, and average student evaluation scores). The top 20% of the faculty scoring the most total points received a 20% pay increase, the next 20% of faculty achievers received a 15% increase, and the next 20%, a10% increase. Achievements were measured for the past year, and the salary increase was given for 1 year. Publications in journals counted for three years to emphasize their importance, and to account for fluctuations in the number of publications from 1 year to the next; the same was done for complete books of faculty members published by a recognized publisher.

Priest et al. (2002) covered the issue of incentive-based budgeting systems in public universities, exploring diverse areas of HE: incentives to faculty, the effect of incentives on teaching, incentives to increase revenue, and efficiency implications at the state level, providing examples from universities in North America. Elson (2017) highlights the issue of financing for gender equality via the budget, in compliance with human rights standards (see also, Steinþórsdóttir et al., 2016).

On the international level, OECD collects data on HEIs from its national members and other countries regarding financial and other performance measures, which indirectly give various countries incentives to improve their performance accordingly. As they claim:

> *Governments are increasingly looking to international comparisons of education opportunities and outcomes as they develop policies to enhance individuals' social and economic prospects, provide* ***incentives*** *for greater efficiency in schooling, and help to mobilise resources to meet rising demands*. (OECD, 2019)

Examples of such indicators in HE are attainment of HE of 25–64-year-olds by gender, by degree, by field of study; labor market outcomes: employment % (unemployment) by level of education, relative earnings, private and public cost benefits, and return on investment in HE by gender. Although no budgeting is directly involved in the OECD report (2019), there is a hidden incentive for countries to allocate more budget or more attention to improve certain performance measures.

There are many possibilities to encourage improvement in HEIs by using various formulas or budgeting rules to foster the desired objective in some budget items. However, these types of incentives should apply for long periods to gain the full cooperation of the targeted population since it takes time, sometimes even years, to implement a new procedure and to learn its implications (ibid.).

9.3.5 Planning in HE Versus Budgeting

Indeed, the budget is a presentation of an HEI plan in monetary terms. However, planning is a much wider term. Planning can be done at any level of the HE system, with or without connection to the budget, financially linked or not. In this subsection, examples of planning that are not tied directly to the budget process are presented.

Planning in subsystems: The above procedures seem to fit the total university, but its principles can also fit subsystems such as library budget allocation—a subsystem that has received great attention in the literature (see examples by Adekanmbi &

Boadi, 2008; Kao et al., 2003; Walter, 2018). Another example is planning the future load of information systems for educational purposes, for which Gorbunov et al. (2017) used a simulation model, and Sinuany-Stern and Yelin (1993) used a regression analysis to forecast computer hardware resources (CPUs, memory, etc.) to avoid bottlenecks at a large university (see also Banerjee & Igbaria, 1993). In addition, Hamid et al. (2018) analyzed space capacity by type (classrooms, labs, offices, etc.) using government standards at a public university in Malaysia by a capacity index.

Sometimes planning in HE does not have monetary implications. For example, Magnanti and Natarajan (2018) used discrete optimization to allocate students to multidisciplinary projects. Timetabling for courses or exams are well-known planning models in which space or manpower such as faculty and courses or exams are placed in time to achieve a specific objective under some constraints. Oude Vrielink et al. (2019) performed a systematic review on optimization models and practices of timetabling in HEIs, showing that, since 1990, the number of articles published on timetabling in HE has grown exponentially.

Garcia (2019) used a multi-objective max-flow model for faculty planning to assist future hiring decisions. Aviso et al. (2019) suggested an optimization model with a P-graph approach for the case of a teaching-oriented HEI that was planning a transition to include research activities. The framework is input/output, reflecting interdependencies among various categories applied to a university in the Philippines (ibid.).

9.3.6 Simulation/Optimization Scheme of Budget Planning in HEI

In HEIs, the most common budget planning is performed mainly at the university level (as reflected in Appendix 1). Budget planning often involves a combination of several operations research (OR) methodologies such as forecasting simulation and resource allocation. For example, student enrollment may be based on the past year's enrollment and the population born 18 years before multiplied by the participation ratio of this cohort in the past. Instructional costs may be based on the predicted enrollment and the student–faculty ratio, and the full-time/part-time mix of faculty for calculating faculty compensation, as shown in Fig. 9.1. Some institutions predict only the incremental changes of some categories such as institutional support, whereas others may use ZBB or PPBS for evaluating capital budget projects, and still others may use responsibility-centered budgeting for the business school.

An overall picture of the budget planning system, as developed in this chapter, is given in Fig. 9.2. The enrollment forecasts influence, future income, and resource requirements. A cost simulation model is utilized for estimating the resource requirements to the desired level of detail (as in Figs. 9.1 or 9.2) by using

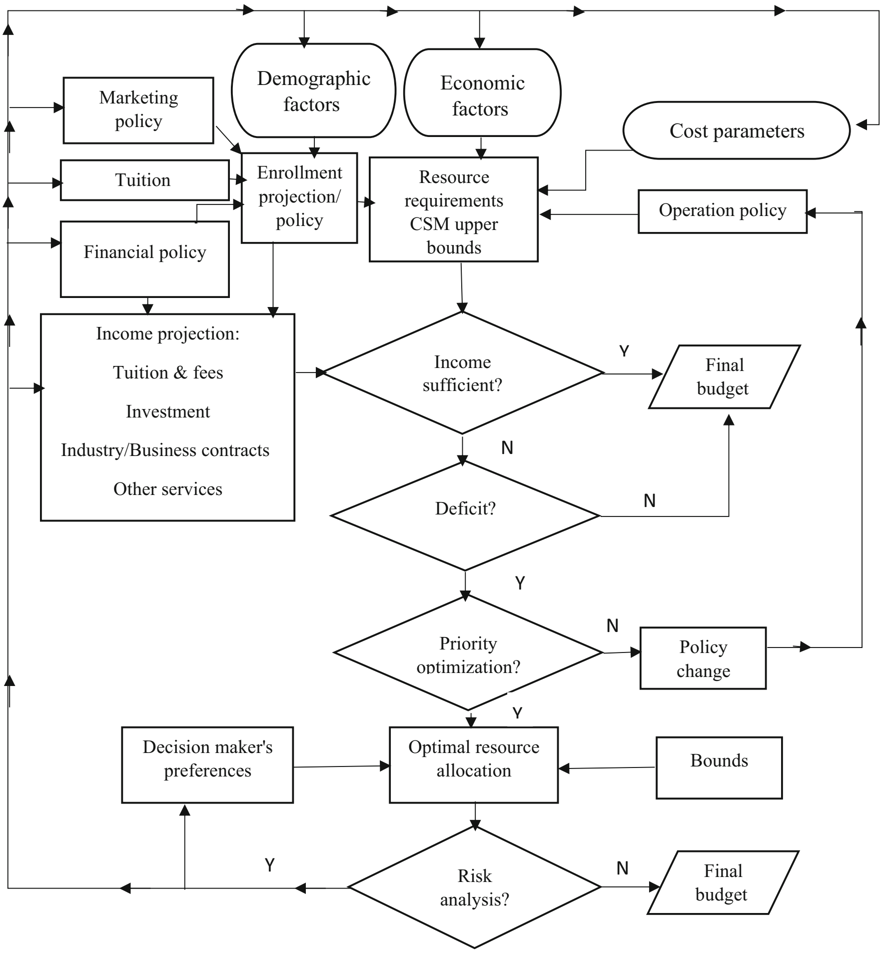

Fig. 9.2 Simulation optimization budgeting planning scheme in a university

cost parameters, and environmental and policy factors. If the expected income is sufficient to cover the resource requirements, then the budget can be approved. Otherwise, the decision-makers can allocate the constrained funds by revising their policy and enforcing their preferences, or by securing additional funds, approving a deficit budget, or using an optimization model. The optimization budget allocation models outlined in Sect. 9.4 maximize the overall objective of the institution based on the decision-makers' preferences (for example, the number of served students), where the sub-expenses from the simulation stage are the upper or lower bounds of each type of expense. The other bound can be the past expenses (incremental growth is possible). After the optimal solution is reached, the final budget can be set; otherwise, risk analyses are performed to test the sensitivity of the optimal solution for various changes in various assumptions and forecasts answering various "what if" scenario changes. The next section provides a variety of optimization budget allocation models, linear and non-linear, for short term and long term planning, and for various levels of HEIs.

9.4 Optimization Models for Budget Allocation

In this section, several types of main optimization budgeting models are presented: linear, quadratic, goal programming, chance constraint, multi-period, and multilevel hierarchical network models. This section is based on Sinuany-Stern (1984b, 1993, 2014).

The basic budget allocation problem is stated as follows: We must allocate a given annual budget to organizational units (e.g., expense items from Fig. 9.1, and/or departments from Fig. 9.2). The allocations of the units may have lower and upper bounds. The upper bounds can be the expense items presented in Fig. 9.1, and the lower bounds can be a certain percentage below each upper bound or previous year allocation (Sinuany-Stern, 2014). If different groups and managers have different estimates for the various expenses, then the lowest estimate of each expense item will be its lower bound, and the highest estimate will be its upper bound.

Here are some definitions:

X_j—the allocation for unit, $j = 1, \ldots, n$ (the decision variables).

n—the number of organizational units.

B—the given total budget B > 0.

Type of constraints:

Budget constraint: $\sum_{j=1}^{n} X_j \leq B$.

Bound constraints (upper and lower bounds):

$$L_j \leq X_j \leq U_j, \quad \forall \ j = 1, \ldots, n.$$

L_j is the lower bound of allocation j, $L_j>0$

U_j is the upper bound of allocation j, $U_j>0$

$\sum_{j=1}^{n} L_j \leq B \leq \sum_{j=1}^{n} U_j$, so that the problem is feasible and nontrivial.

Weights of the objective function:

W_j is the weight (e.g., reward or level of output such as the number of students) associated with one unit of X_j. For simplicity, let us assume that the organizational units are ordered decreasingly, so that $W_j > W_{j+1}$,

$\forall j = 1, \ldots, n-1$ .... For example, if the units are academic departments, then the weights can be the percentage of students in each department. Such weights are used in all the linear models throughout this section, at all hierarchical levels. The weights may represent preferences of decision-makers such as AHP (Sinuany-Stern, 1984b).

The bounds represent two extreme scenarios for the expected allocations of each unit: the minimal allocation and the maximal. In practice, often the lower bounds are derived from historical allocations of the budget, while the upper bounds are derived from budget requests of the units. The bounds may reflect forecasts calculated by various parties in the organization. The minimal scenario of these forecasts may serve as the lower bound, and the maximal as the upper bound (e.g., student forecasts). In Sect. 9.3, a number of methods are shown from which the bounds can be generated, including forecasting methods, planning models, and simulation approaches to determine the needs of various units in a university that help to set the bounds on the allocations (see also, Sinuany-Stern, 1983b, 1984a).

9.4.1 Linear Model with One Period and One Hierarchical Level

The objective function is linear, maximizing the overall reward from the sum of allocations:

Max$\sum_{j=1}^{n} W_j X_j$, where W_j is a positive weight associated with one unit of X_j . In this case, there are four sub-models:

1a. *Linear model with no constraints*: The solution is to allocate infinity to each unit.
1b. *Linear model with only budget constraints*: The solution is to allocate all the budget B to the first unit (since it has the highest weight).
1c. *Linear model with budget constraints and bounds on the allocations*: The solution procedure is: 1. Allocate the lower bounds to all units as the initial allocation. 2. Add allocations up to the upper bound starting with unit 1. Check if there are leftover funds of the total budget, and if so, continue to the next unit in order till reaching unit j*, where we exceed the budget. Then this unit will be allocated only to the remaining budget, and all units thereafter will receive no additional allocation beyond the lower bound.
1d. *Linear model with only bound constraints* (no budget constraints): The solution is to allocate the upper bound for each unit.

The detailed formulations of each model are given in Table 9.1. These formulations are not necessary for non-analytical decision-makers. The solutions are simple and intuitive (as listed above), and do not require mathematical calculations. The optimal solutions of linear objectives with linear constraints are at extreme points of the constraints, mostly either at the bounds or infinity. See Example in Appendix 2.

The last column of Table 9.1 provides the change in the allocations when a budget cut occurs. Budget cuts affect only one unit, for a linear objective function. Again, the solutions are intuitive and require simple arithmetic calculations.

In summary, the solutions of linear objective functions are extreme and seem unfair (see Sinuany-Stern, 2014 on fairness). Thus, the following subsection presents a nonlinear objective function—the quadratic objective function.

Table 9.1 Formulations and solutions of linear models with one period and one hierarchical level

The objective is to find X_j to maximize : $\sum_{j=1}^{n} W_j X_j$			
Sub-model	Constraints (const.)	Solution	Solution for budget cut of ε
1a	None	$X_j = \infty$, $\forall j = 1, \ldots, n$	No change in the solution
1b	Budget const. $\sum_{j=1}^{n} X_j \le B$	$X_1 = B$ $X_j = 0,\ \forall j = 2, \ldots, n$	$X_1 =$ $B - \varepsilon$ $X_j = 0,\ \forall j = 2, \ldots, n$
1c	Budget const. $\sum_{j=1}^{n} X_j \le B$ Bounds const. $L_j \le X_j \le U_j$, $\forall j = 1, \ldots, n$	$X_j = U_j,\ \forall j = 1, \ldots,$ $j^* - 1$ $X_j = L_j,\ \forall j = j^* + 1,$ $\ldots, n$ $X_j* =$ $B - \sum_{j=1, j \ne j*}^{n} X_j$	Only X_{j*} reduces by: ε
1d	Bounds const. $L_j \le X_j \le U_j$, $\forall j = 1, \ldots, n$	$X_j = U_j$ $\forall j = 1, \ldots, n$	No change in the solution

9.4.2 Quadratic Model with One Period and One Hierarchical Level

The quadratic model attempts to minimize the distance of each allocation from its bounds in order to avoid extreme solutions. This subsection is based on Sinuany-Stern (2014). Table 9.2 presents several types of quadratic models within our general framework as described above, considering a budget constraint and lower and upper bounds on the allocations of the various units. The objective function is common to all the quadratic models presented in this Sect. 9.4.2, as follows:

$$\text{Min} \sum_{j=1}^{n} q_j \left(\left(X_j - U_j \right)^2 + \left(X_j - L_j \right)^2 \right)$$

As a minimization objective function, the weights, q_j, reflect a penalty on deviation from the bounds. For example, the reciprocal value of the weight can be used, $q_j = 1/W_j$, giving higher preference to units with lower q_j, which are in fact units with higher W_j. For example, if W_j represents the number of students, then units with more students (greater W_j) will have preference in the allocation, and also in the quadratic model since their q_j will be lower. For example, if there are two units in a college where unit 1 has 200 students and unit 2 has 100, then $W_1 = \frac{200}{300}$ *and* $W_2 = 100/300$; consequently, $q_1 = \frac{1}{W_1} = 3/2$ and $q_2 = \frac{1}{W_2} = 3/1$.

Following are three sub-models derived here for the quadratic objective model with the constraints used for the linear model.

2a. *Quadratic objective function with no budget constraint*

Model 2a presents a special type of goal programming approach, where there is no budget constraint and the upper and lower bounds are soft constraints with a quadratic penalty, rather than linear with the deviation from the bounds. The total penalty is the sum of the weighted deviations to be minimized—the weights are q_j , $\forall j = 1, \ldots, n$. The optimal solution in this case is the midpoint between the bounds. The sum of the optimal allocation can be used as a suggested total budget: $B = \sum_{j=1}^{n} \left(\frac{L_j+Uj}{2}\right)$.

2b. *Quadratic model with only budget constraint*

Model 2b adds the budget constraint to Model 2a. As shown in Table 9.2, the solution is quite intuitive: Start with the initial assignment of the midpoint to each unit j. If the sum of the midpoints is less than the budget B, then the sum left over from the initial assignment of the budget, $\overline{B}$, is reallocated to each unit j proportionally to $1/q_j$ and added to the original midpoint assignment.

If there is a shortage after the initial assignments; namely, $\overline{B}$ <0, then the shortage in the budget is distracted from the original midpoint assignment.

2c. *Quadratic model with budget and bounds constraints*

Model 2c is similar to model 2b, but in addition, there is a need to verify that the bounds are met: If the upper bound of unit j is violated, then set $X_j = U_j$, and if the lower bound of unit j is violated, then set $X_j = L_j$. The overall leftover sum/deficit after accounting for the bounds will be divided among the units that did not reach any of their bounds.

Table 9.2 Solution of linear model with one period and one hierarchical level

The objective is : find X_j *to* minimize $\sum_{j=1}^{n} q_j \left((X_j - U_j)^2 + (X_j - L_j)^2\right)$			
Sub-model	Constraints (const.)	Solution[a]	Solution for budget cut of ϵ
2a	None	Midpoint allocation: $X_j = \frac{L_j+U_j}{2}, \forall j = 1, \ldots, n$	No change
2b	Budget const.: $\sum_{j=1}^{n} X_j = B$	Midpoint allocation + its proportional share from leftover sum[a]: $X_j = \frac{L_j+U_j}{2} + \left(\frac{1/q_j}{\sum_{j=1}^{n} 1/q_j}\right)\overline{B}$	Cut across the board: $X_j^{'} = X_j - \left(\frac{1/q_j}{\sum_{j=1}^{n} 1/q_j}\right)\epsilon$, $\forall j = 1, \ldots, n$
2c	Budget const.: $\sum_{j=1}^{n} X_j \leq B$ Bound const.: $L_j \leq X_j \leq U_j$, $\forall j = 1, \ldots, n$	As in 2b, but if the bound is violated, then force the bound, and the leftover sum/deficit will be divided proportionally to $1/q_j$ for other units j that are within the bounds	As above, cut across the board, but verify the bounds as in the previous column

[a] *Left over from midpoint allocation:* $\overline{B} = B - \sum_{j=1}^{n} \left(\frac{L_j+Uj}{2}\right)$

The detailed formulations of each model are given in Table 9.2. These formulations are not necessary for non-analytical decision-makers. The solutions are simple and intuitive and those of quadratic objectives with linear constraints are mostly at the midpoints of the constraints. See example in Appendix 2.

A quadratic objective function was also used by Bogomolova et al. (2018) to find the optimal annual growth rate of a budget allocation for research in a university, which minimizes the sum of the square deviation of the allocation from the prediction over time.

9.4.2.1 Fairness of the Quadratic Versus the Linear Models for Budget Allocation

As shown in Table 9.1, the linear budgeting models provide extreme budget allocations; almost all units will have allocation on one of the bounds (lower or upper bound). However, as shown in Table 9.2, the quadratic budgeting models provide more fair solutions, mostly between the bounds. Sinuany-Stern (2014) defined a fairness index for budget allocation with bounds and proved mathematically that the quadratic model is fairer than the linear model. This gives the various participants in the budgeting process some security that they have a fair chance in the budget allocation, and more so when the lower bound is based on the needs of the units and is tied with the performance level, be it enrollment or research outputs. Moreover, budget cuts are distributed more evenly among the various units in the quadratic model, while the budget cut in the linear model tends to cut the allocation of only one unit.

9.4.2.2 Dynamic Quadratic Budget Allocation with Only Bounds Constraints

In cases when, historically, a unit was overbudgeted and the lower bound represents the real needs of the unit, the quadratic allocation is at the midpoint between the lower and upper bounds. However, if there is no budget constraint (the budget is the sum of the midpoint solutions), then to reduce the specific units' allocations without a drastic cut, we apply the quadratic model over time, so we can speed the approach of the allocation to the lower bound by setting the allocation of year t as the upper bound of the consecutive year dynamically from year to year. Meanwhile, the lower bound will remain unchanged. After one year, 50% of the gap between the bounds will be achieved (the midpoint), after 2 years 75% of the gap between the original bound will be achieved (the midpoint of the second year's bounds), and after 3 years, 87.5% of the original gap will be corrected (see details by Sinuany-Stern, 2014). The general formula for the allocation of unit j over time t is: $X_{jt} = \frac{(2^t-1)L_j+U_j}{2^t}$ (e.g., for t = 1 the allocation is at the midpoint between the original bounds). A similar method can be used for a unit that is underbudgeted. This dynamic approach of correcting the allocations over time may motivate overbudgeted units to improve their performance to justify a higher allocation (if at least the lower bound is positively related to the performance level). Any decision-maker will be satisfied to achieve 75% of a budget correction within 2 years.

9.4.2.3 Goal Programming and Absolute Value of the Objective Function

Case 2a is like a goal programming model with no hard constraints (no budget constraint), where the goals are the bounds, and the deviation from the goal is quadratic.

The absolute value model, where the objective function is the absolute value of the deviations from the bounds rather than a quadratic function without constraints provides a similar solution to the quadratic model, namely, allocation to the midpoint of each unit.

9.4.3 Linear Two-Level Hierarchical Budgeting Model Over Time

This model deals with budgeting over T years in a hierarchical system with two levels (e.g., college level and department level). This subsection is based on Sinuany-Stern (1984b). The objective function is linear with the allocations, *X,* and the weights, *W,* representing the preference (importance) of the relevant unit (can be proportional to the number of students in each unit at each level). The allocation of year *t* is X_t.., the allocation of college *k* in year *t* is X_{tk}, and the allocation to department *j* at campus *k* is X_{tkj}. All allocations $X\ldots$ have lower and upper bounds, L_t.., U_t.., where the anticipated income of year t is B_t; a_i is a weight given to the *i*th level of the institutional hierarchy, $i = 1, 2, 3$; and D_t is the surplus carried from year t to year $t + 1$. Where $t = 1, \ldots, T$; $k = 1, \ldots, K$; $j = 1, \ldots n$. *T* is the planning horizon (in years), *K* is the number of campuses, and *n* is the number of units at each campus.

The objective function is to find X_{tkj}, X_{tk}, and X_t such that:

$$\text{Max}\left[a_1\sum_{t=1}^{T} W_t..X_t.. + a_2\sum_{t=1}^{T}\sum_{k=1}^{K} W_{tk}.X_{tk}. + a_3\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{j=1}^{n} W_{tkj}X_{tkj}\right]$$

Subject to:

Balance constraints in the two organizational levels:

$X_t.. = \sum_{k=1}^{K} X_{tk} \quad, t = 1, \ldots, T$

$X_{tk\cdot} = \sum_{j=1}^{n} X_{tkj}$, $t = 1, \ldots, T; k = 1, \ldots, K$

Budget constraint:

$X_{t\cdot\cdot} + S_t - S_{t-1} = B_t$

$\sum_{m=1}^{t} X_m \leq \sum_{m=1}^{t} B_m, t = 1, \ldots, T$

Lower and upper bounds on allocations:

$L_{t\cdot\cdot} \leq X_{t\cdot\cdot} \leq U_{t\cdot\cdot}$, $t = 1, \ldots, T$

$L_{tk\cdot} \leq X_{tk\cdot} \leq U_{tk\cdot}$, $t = 1, \ldots, T; k = 1, \ldots, K$

$L_{tkj} \leq X_{tkj} \leq U_{tkj}$, $t = 1, \ldots, T; k = 1, \ldots K; j = 1, \ldots, n$

$\sum_{t=1}^{T} W_{t\cdot\cdot} = 1$, $\sum_{k=1}^{K} W_{tk\cdot} = 1$, $\sum_{j=1}^{J} W_{tkj} = 1$

The various weights, W, are normalized so that only a_i reflects the weights given to each level. This model can be solved as a linear programming model of a capacitated network model. The two-level hierarchical linear network budgeting model over time presented here is sometimes too cumbersome mainly because the bounds setting over each period for two hierarchy levels (usually a 5-year plan) is taken. For example, if at a small comprehensive university, we have: five colleges, five academic departments in each college, and five functional areas in each college, then for a 5-year plan, we need to estimate at least 500 bounds! (5x(5 + 5)x5x2 = 500) see general formula in Sinuany-Stern (1993, p. 301).

Therefore, in the long run, a very aggregated model is more practical (as shown in Sect. 9.5). Moreover, in practice usually, budget allocation is done for one year ahead, while long-run planning is usually done for the aggregated level to learn the long-run implications of current allocations over time, not for actual allocations for the long run by units and subunits.

9.4.4 Linear Multilevel Hierarchical Linear Network Budgeting Model

This section deals with a single year's budget allocation in a multilevel hierarchical system with N levels, where the objective function is linear, with upper and lower bound constraints on each allocation, and a constrained budget B to be allocated. Due to the hierarchical structure, naturally, there are also balanced constraints, where the sum of the allocations in one level is the allocation of the upper level (based on Sinuany-Stern, 1993) as shown in Fig. 9.3.

Let us assume that we have N hierarchical levels (e.g., three levels: the university level, the college level, and the department level). For each level I, there are J_i units under it, the weight given to level i is a_i , where $i = 1 \ldots N$; $X_{j_1,\ldots,j_i}$ are the allocation to unit j_i in level i, and $W_{j_1,\ldots,j_i}$ is the unit weight of the allocation to unit j at level i—the weight can be proportional to the number of students. The

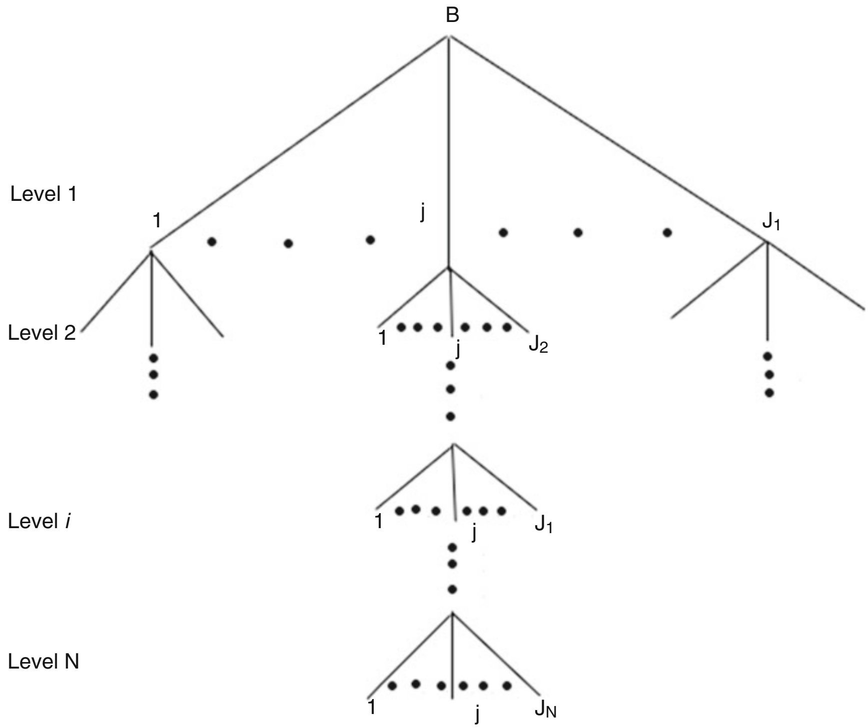

Fig. 9.3 Multi-hierarchical structure

objective function is linear:

$$\max\left\{\sum_{i=1}^{N} a_i \sum_{j_1=0}^{J_1}, \ldots, \sum_{j_i=0}^{J_i} W_{j_1,\ldots,j_i} X_{j_1,\ldots,j_i}\right\}$$

Subject to:
Budget constraints:

$$\sum_{j_1=0}^{J1} X_{j_1} \leq \mathrm{B}$$

Balance constraints at all organizational levels from level $i + 1$ to level i:
$X_{j_1,\ldots,j_i} = \sum_{j_{i+1}=0}^{J_{i+1}} X_{j_1,\ldots,j_{i+1}}$; for all $i = 1, \ldots N$ and $j = 1 \ldots Ji$
Upper and lower bound constraints on each allocation:
$L_{j_1,\ldots,j_i} \leq X_{j_1,\ldots,j_i} \leq U_{j_1,\ldots,j_i}$; for all $i = 1, \ldots N$ and $j = 1 \ldots Ji$

This type of network multi-hierarchy model fits a centralized budget. Linear programming simplex can solve it or a more efficient cost-capacitated network algorithm. In general, the number of balance equations is $T \sum \prod_{k=1}^{i} J_k$. The number of variables is the same, as is the number of lower and upper bounds.

Sinuany-Stern (1993) showed several developments and generalizations of this model: a. If the objective function is nonlinear, in some cases, it can be linearized by piece-wise linearization (ibid., pp. 302–304); b. multi-criteria objective considering can be used via AHP (analytical hierarchy process; Saaty & Vergas, 2012) for evaluating the preferences, *Wj*, as suggested by Sinuany-Stern (1984b, pp. 301–302); and c. including zero, one variable is possible when projects are to be considered in the allocation process (ibid., p. 305).

9.4.5 Chance Constraint

In each of the above models, a chance constraint can be introduced to account for randomness. For example, if the budget level is distributed normally with expected value B and standard deviation σ, then the following budget constraint reflecting a 95% one-sided confidence interval is: $\sum_{j=1}^{n} X_j \leq B + \sigma \bullet z(0.95) = B^{"}$ where z(0.95) =1.645 is the value of the standard normal distribution where Prob.(Z < z(0.95)) = 0.95. The original budget constraint will simply change to:

$$\sum_{j=1}^{n} X_j \leq B^{"}.$$

Namely, in each of the above models and sub-models, the change will be in the budget constraint by replacing B by B″, and the change will be in the solutions. Wherever B appears, it will be replaced by B″.

9.5 Aggregated University Long-Run Budget Planning Model

Long-run financial planning is usually based on aggregated incomes and expenses (Sinuany-Stern, 1983a). In the extreme aggregation: I_t is the total income of an HEI at period t, and E_t is the total expenditure of an HEI at period t. Usually, the period used in budget planning is a "year" although any time unit can be used: semester, quarter, etc. In long-run budget planning, an HEI may carry funds or a deficit from year *t-1* to year *t.* In this case, we consider, *r,* the rate of return on the university's excess (or deficit) funds (the rate of interest). For simplicity, we can assume that *r* is the same for investment and for deficit, since often in HEIs there are endowment funds whose annual returns are part of the HEI income, and a deficit in the budget can be taken from those funds, while excess budget is invested back into the endowment funds. From one year to another, the following difference equation describes the dynamics of the budget progression and its deficit/over D_t, where

$$D_t = I_t - E_t + (1 + r)\, D_{t-1}$$

There are many types of mathematical models for describing the progression of income and expenses of budgets over time, as shown in Table 9.3, where seven models are described. These mathematical models are simple enough for administration in HEIs, and as presented in the table, the differences between them is very clear:

Model 1 presents an incremental increase in the income and expenses of an HEI; namely, linear constant growth in income and expenses from one year to the next.

Model 2 presents a constant percent of growth in income and expenses, namely, an exponential growth of income and expenditures over time. In both models, the constant between two consecutive years does not change (*a, b*), while in

Model 3, the change varies over time (a_t, b_t).

Model 4 has another general formula for the change of income and expenses over time [I(t), E(t)], and

Model 5 allows for another growth parameter such as student growth or decline. While

Models 1–5 are highly aggregated,

Model 6 allows a breakdown of the income (e.g., tuition, state, endowment, grants) and expenses (e.g., instructional costs, student services, financial aid, physical plant operation costs).

Model 7 considers a continuous rate of change over time; thus, it is in an integral form, whereas the other six models are summative (see Sinuany-Stern, 1983 for more details about additional models).

The above difference equation expressing for D_t, the deficit/surplus is applicable to each of the above seven models.

The connection between the traditional budgeting procedures and the models in Table 9.3 are given in the first column: Models 1–3 and 5 are types of incremental budgets, and Model 4 is a formula type budgeting. All seven models in the table are applicable to all organizational levels (department, school, college, university, and state) of an HEI. Incremental budgets are often used, while formula budgets are more applicable at the state level.

Taking a closer look at Model 2, for example, we can analyze the progression of the deficit/surplus by applying the geometric growth of income and expense equations to the above definition of D_t. It becomes:

$$D_t = I_0 \frac{(1+a)^{t+1} - (1+r)^{t+1}}{a-r} - E_0 \frac{(1+b)^{t+1} - (1+r)^{t+1}}{b-r}.$$

Thus, a break-even analysis can be done for $D_t = 0$, implying conditions for convergence on the relations among the various parameters of the model; see Sinuany-Stern (1983b) for full derivations. Models for the case of uncertainty represented by probability density functions are also given there (ibid.).

In the long-run planning range, which can be for any number of years, it is usually by breakdown of income and expenses, and often for 5 years. For example, Brandeau et al. (1987) used a set of equations of various types of incomes and expenses by department within a medical school as RCB within a private university (Stanford) for a 5-year plan. Many of the equations predicted the annual increments

Table 9.3 Examples of analytic models for annual progression of income and expenditures

Model no.	Nature of *I, E* progression over time	Income – I_t	Expenditure – E_t
1	Incremental linear growth	$I_t = I_{t-1} + a = I_0 + ta$	$E_t = E_{t-1} + b = E_0 + tb$
2	Incremental with constant rate and geometric/ exponential: *a, b*	$I = (1 + a)I_{t-1} = (1 + a)^t I_0$	$E_t = (1 + b)E_{t-1} = (1 + b)^t E_0$
3	Incremental with variable rates over time, a_t, b_t	$I_t = (1 + a_i)\, I_{t-1} = I_0 \prod_{i=1}^{t} (1 + a_i)$	$E_t = (1 + b_i)\, E_{t-1} = E_0 \prod_{i=1}^{t} (1 + b_i)$
4	Formula budget as a function of *t*	$I_t = I(t)$	$E_t = E(t)$
5	Incremental as model 2 with additional constant growth -g (e.g., student enrollment)	$I_t = (1 + g)(1 + a)I_{t-1} = [(1 + g)(1 + a)]^t I_0$	$E_t = (1 + g)(1 + b)E_{t-1} = [(1 + g)(1 + b)]^t E_0$
6	Breakdown of I and E are given over time (KA and KB categories)	$I_t = \sum_{k=1}^{KA} I_{kt}$	$E_t = \sum_{k=1}^{KB} E_{kt}$
7	Continuous rate is used over the year	$I_t = \int_t^{t+1} I(x)dx$	$E_t = \int_t^{t+1} E(x)dx$

[a]*In Models 1–5, the expenses and income are discrete,* i.e.*, they occur at one point during the year*

of specific types of income/expenses with varying enrollment rate of change, etc. combining Models 4, 5, and 6 (Table 9.3). This was basically a simulation model testing the effect of various assumptions (not optimization) on the 5-year budget plan (ibid.).

9.6 Summary and Conclusions

As Zierdt (2009) declared: "*The literature suggests that institutions need to choose a budgeting tool that is most reflective of their needs and strategic priorities. It seems likely, therefore, that a hybrid approach to budgeting will become the norm within institutions of higher education, especially with the increased demand for reform of how scarce resources are allocated.*"

This chapter proves that the above statement is unavoidable. We started by outlining the five main traditional (non-mathematical) approaches used in HE budgeting: Incremental, ZBB, PPBS, Formula, and RCB. The second stage, estimating expenses and incomes of HEI via several methods and formulas (ratio, regression, increase by percentage, etc.) and a simulation/optimization budgeting scheme was presented, where if the income is insufficient, a scenario risk analysis can be done by analyzing various "what if" questions. If still the budget is not sufficient, an optimization model can be used, with lower and upper bounds on the allocation taken from the simulation model. Several linear models were analyzed, also in hierarchical network structure (10 variations), and a quadratic model with three variations was presented. We showed that the solutions of the optimization models are simple and intuitive, and do not require mathematical skills. The bounds on the allocations can be a combination of the simulation approach and some of the above traditional budgeting procedures. The optimal solution of the linear model is to allocate to all the units on the upper or the lower bound except for one marginal unit, while the solution of the quadratic model is to allocate to the midpoint between the bounds. Consequently, the allocation of the quadratic model is more intuitive and fairer than the allocations of the linear model. For the long run, an aggregated model was presented with many functional forms (7 variations). These models are also connected to the above traditional budgeting procedures.

Massy's (2017) book on reengineering the university: *How to be Mission Centered, Market Smart, and Margin Conscious* is applicable today, especially with the COVID-19 pandemic, which provides many opportunities for using short-run and long-run planning, mainly of online and web-based tools (e.g., Zoom). Moreover, new forms of virtual classrooms and virtual universities are expected to evolve (see Almog & Almog, 2020).

Appendix 1: Summary of the Literature on Planning and Budgeting in HE

Author (year)	Method used	Type of planning/budgeting	HE area	Levels HE hierarchy	Country
Balderston and Weathersby (1972)	PPBS	Program planning & budgeting		University	USA
Weathersby and Balderston (1972)					
Sinuany-Stern (1983a)	Break-even aggregate, income vs. expense equations	Increment budgeting	Long-run planning	University	USA
Sinuany-Stern (1983b)	Simulation, system analysis approach	Budgeting	Costing	University	USA
Sinuany-Stern (1984a)	Budget planning procedure; Projections & Scenario analysis	Budgeting & planning	Financial planning model	Multi-campus university	USA

(continued)

Author (year)	Method used	Type of planning/budgeting	HE area	Levels HE hierarchy	Country
Sinuany-Stern (1984b)	Network optimization linear with bounds and budget constraint	Budgeting	Budget allocation over time	Multi-campus university	USA
Brandeau et al. (1987)	Set of equations predicting incremental change in expenses & revenues by dept.	RCB & increment budget for 5 years	Budgeting & planning, cost (in a private university)	Medical school by department	USA
Whalen (1991)	Decentralized management of HEI	Responsibility-center budgeting		HEI	USA
Banerjee and Igbaria (1993)	Questionnaire/ survey	Computer capacity planning		National	USA
Sinuany-Stern and Yelin (1993)	Regression	Hardware resources (CPU, memories, etc.)		University	Israel
Sinuany-Stern et al. (1994)	Data envelopment analysis (DEA)	Efficiency and planning academic departments		University	Israel
Thomas (1999)	System of resource allocation	Formula-based budgeting		HEI	UK
Priest et al. (2002)	Review	Incentive-based budgeting		Pub. Univ.	General
Kao et al. (2003)	Decision support allocation model via circulation data mining	Library acquisition budget	Decision-making, budget allocation	University library	Taiwan
Adekanmbi and Boadi (2008)	Questionnaire to study libraries budgeting	Budgeting	Library resource acquisition	Libraries at 6 teaching colleges	Botswana

(continued)

Author (year)	Method used	Type of planning/budgeting	HE area	Levels HE hierarchy	Country
Nicholls (2009)	Markov models	Planning & benchmarking doctoral progression		University	Australia
Zierdt (2009)	Responsibility-centered budgeting			HEI	USA
Trusheim and Rylee (2011)	Cohort-survival, percentages by type of student	Enrollment prediction & tuition income		University	USA
Frank (2012)	Formula mainly by discipline per student	Formula budgeting	State allocation	National	Israel
Tang and Yin (2012)	Grey models better than exponential smoothing	Education expenditure & student enrollment		National	USA
Agboola and Adeyemi (2013)	Ratio method & fixed annual percent	Student forecast for faculty planning		National	Nigeria
Ekanem (2014)	Questionnaire on ZBB—Descriptive statistics	Zero-based budgeting (ZBB)	To verify staff opinion on ZBB	University	Nigeria
Cheporov and Cheporova (2015)	Time equations activity-based costing	Formula budgeting	Student/faculty ratio is too low	University	Ukraine
Sweeney et al. (2016)	Educational data mining, regression, factorization machine	Strategy planning	Student planning—Retention, by grade prediction	National	USA
Davidovitch et al. (2016)	Regression	Criteria for faculty incentive for teaching & research excellence		University	USA
Soares et al. (2016)	General evaluation	Activity-based costing for community college		HEIs	USA
Philbin & Mallo, 2016	MSP (managing successful programs)	Strategic planning	Investing in new research facility	University in cooperation	United Kingdom

(continued)

Author (year)	Method used	Type of planning/budgeting	HE area	Levels HE hierarchy	Country
Steinþórsdóttir et al. (2016)	Case study	Budgeting	Gender needs	University	Iceland
De La Torre et al. (2016)	Mix integer linear programming (MILP)	Planning	Long-term faculty size & composition	Public universities	Spain
Gorbunov et al. (2017)	Simulation model, using AnyLogic (deterministic)	Private cloud vs. university's own server	Planning future info. Sys. Load for ed. purposes, facility planning	University	Russia
Bogomolova et al. (2017)	Correlation between economic factors and budgeting of science	Planning & budgeting	Budgeting science in universities	National	USA and Russia
Kenno and Sainty (2017)	Heuristic inquiry and content analysis	Activity-based budgeting	Resource allocation	University	Canada
Xiao and Chankong (2017) simulation	System dynamics	Demand & supply forecast of students (medical talents)		National	China
Hamid et al. (2018)	Survey listing space by type of facility (labs & classroom) by government standards	Space capacity, facility, & efficiency	Facility planning, performance strategy	Public universities	Malaysia
Walter (2018)	Case study to promote strategic cooperation of library users	Strategic planning	Facility planning, strategy	University library	USA
Bogomolova et al. (2018)	Optimization model—Quadratic	Budgeting	Resource allocation	Universities, national	Russia
Magnanti and Natarajan (2018)	Discrete optimization	Allocating students to multidisciplinary projects		School of engineering	Singapore

(continued)

Author (year)	Method used	Type of planning/budgeting	HE area	Levels HE hierarchy	Country
Aviso et al. (2019)	P-graph model	Human resource	Planning, resourcing, quality	National	Philippines
Garcia (2019)	Multi-objective max-flow	Scenario analyses	Optimal resource allocation	College of business	USA
Myers (2019)	Moral hazard mathematical program	Responsibility-centered budgeting		University	USA & Canada
Oude Vrielink et al. (2019)	Timetabling	Planning	Course, exam, class, faculty	HEI	General review
Smith (2019)	Review	HE accounting & budgeting		HEI	General
Henry-Moss et al. (2019)	Online survey	Lactation facility for breast feeding	Service campus facilities for women, better accessibility	National Community colleges	USA
Wardhani et al. (2019)	Regression, employee's questionnaire methods on good governance in budgeting & planning	Participation & budget control importance	Strategy, planning, budgeting	University	Indonesia

Source Google scholar (assessed during 2020)

Appendix 2: Example for Linear and Quadratic Budget Allocation Modes

Assume we have 6 schools in a university. The first 3 columns of Table 9.4 present the number of students, the upper and lower bounds of the allocations to the schools, where the lower bounds are based on cost analyses, where the upper bounds are the requests of the schools. The schools are ordered according to their number of students.

Under budget constraint and bounds constraints: the *linear* model allocates to the first four schools their upper bound and to the other schools, with a lower number of students, only their lower bound is allocated, as shown in the fifth column, according to model 1c in Table 9.1. First, the lower bounds are allocated to each school, afterwards the first schools get addition to their upper bound are reached till the budget is finished, the rest of the schools do not get any additional budget beyond their lower bound.

While the *quadratic* model allocates between the bounds according to model 2c in Table 9.2 not exactly in the middle of the midpoint, as shown in the seventh

Table 9.4 Linear and quadratic budget allocation under bounds and limited budget[a]

Schools	Student #	bounds		Weights of students	Linear allocation: limited budget of 74,000		Quadratic allocation: limited budget 74,000	
		lower	upper		limited	not	limited	not
Liberal arts	2000	30, 000	32, 000	0.360	32,000	32, 000	31, 072.0	31, 000
Engineering	1000	11, 200	12, 000	0.180	12,000	12, 000	11, 636.0	11, 600
Business	840	5600	6000	0.151	6000	6000	5830.2	5800
Social sci.	800	10, 000	10, 800	0.144	10,800	10, 800	10, 428.8	10, 400
Sciences	600	5200	7200	0.108	5200	7200	6221.6	6200
Health sci.	320	8000	9600	0.057	8000	9600	8811.4	8800
Total	5560	70, 000	77, 600	1.000	74,000	77, 600	74, 000.0	73, 800

[a] All figures in the table are in thousands

column. After initial allocations in the midpoints, the leftover added to each school proportionally to their number of students.

When there are no budget constraints, but there are bound constraints, then in the *linear* model, each school receives its upper bound, according to model 1d, as shown in Column 6.

While the *quadratic* model allocation to each school is in the midpoint between the bounds, as shown in Column 8. To simplify the calculation the president of the university can set the budget to be allocated according to the eighth column with a total of $73,800,000, and leave the leftover $200,000 (74,000,000 − 73,800,000) for unforeseen costs.

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Part II
New Methodologies

Chapter 10
Funding Research in Higher Education Institutions: The Game Theory Approach

Baruch Keren, Yossi Hadad, and Yizhaq Minchuk

Abstract This chapter presents a unique model, based on game theory, that can help decision-makers in higher education (HE) institutions determine an optimal research budget. The model can then help them decide how to allocate that budget among academic units such as researchers, institutions, and departments. The model considers the management of the institution as a contest organizer and the academic units as contestants that compete with each other to win the contest. The prize of this contest is a desired research budget. The proposed model includes a form of two contestants with different abilities, as well as a form with unlimited (N) contestants with the same abilities. The model enables decision-makers to determine the size of the optimal research budget (the prize), and the optimal distribution mechanism (a contest or a budget division) of that prize among the contestants. To the best of our knowledge, determining the size of the Tullock contest prize according to the contestants' abilities with comparison to a bargaining model has not previously been studied. This is an application that is new to the HE budget allocation process. The study includes a numerical example that demonstrates the model and its applicability.

Keywords Contest · Game theory · Budget division · Higher education · Academic units · Research funding · Analytical Hierarchical Process (AHP)

10.1 Introduction and Scientific Background

One of the principal challenges of government is the promotion of higher education (HE). Realization of this challenge can be met by increasing the accessibility of the population to academia, to high-quality teaching, and to international research

B. Keren · Y. Hadad (✉) · Y. Minchuk
Department of Industrial Engineering and Management, SCE—Shamoon College of Engineering, Beer Sheva, Israel
e-mail: baruchke@sce.ac.il; yossi@sce.ac.il; yizhami@sce.ac.il

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excellence. To achieve these goals, an appropriate budget must be provided to HE institutions and they, of course, must use it wisely. Setting the right budget and determining its partition among the needs of the institution should be done while taking into account all relevant considerations and constraints in order to achieve a good balance between various aims and goals. At the system level of HE, competition can be divided between exclusivist elite institutions and mass institutions; the former produce high-value positional goods, where demand always exceeds supply and expansion is constrained to maximize status, while the latter are characterized by place-filling and expansion (Marginson, 2006).

HE institutions usually receive the majority of their funding from public sources, but private funding also plays an important role in HE. Many governments use competitive elements in the process of allocating public funds to institutions of HE. Examples include the implementation of performance measures through a "funding formula," or resource allocation on the basis of evaluated project proposals (Liefner, 2003). Governments exert significant effort to build proper funding mechanisms (budget size, allocation, and regulation) for HE in order to receive maximum impact from that funding in the future (King, 2000). There are several forms of budgeting allocations in HE that have been employed over the years. The allocation might be as simple as division by specific criteria or may involve the use of a more sophisticated mechanism. In recent years, many governments adopted performance-based funding (Nisar, 2015). While one of the main purposes of this form of budget allocation is to increase competitiveness between universities and colleges, given the complex nature of the HE system, those strategies have limited effect (Niklasson, 1996; Nisar, 2015). Internal allocation of resources in some universities and colleges is also competition-based (Liefner, 2003).

Massy (1996) suggested that it is obvious that one should just put the money where it will do the best. He questioned whether, in the most prestigious universities, it was obvious that one should hire the best possible faculty and then step back and let them do their jobs. He wondered why good results could not be reliably attained simply by deciding what programs are most in need of funding and giving them the money. Massy concluded that making the right decision is not that simple and that even when common sense is coupled with knowledge and discipline, institutions are not always sufficiently able to distinguish good processes from bad.

Israel, for example, has an independent body called the "Planning and Budgeting Committee" (PBC), which is preparing and overseeing Israel's HE budget. The functions of the PBC were set in accordance with a 1977 government decision and include proposing HE budgets while taking into consideration the needs of society and the state, safeguarding academic freedom, and observing due diligence for research and instruction. In connection with these responsibilities, the PBC has the exclusive right to allocate regular and development budgets between the institutions of HE. The PBC exercises these rights in order to promote efficiency in the institutions of HE and to monitor the utilization of budgets in order to prevent deficits. In general, there are two budget types that HE institutions receive from the PBC—a global block grant (the main budget), and a budget that is based on outputs (the competitive part). In 2012, the PBC established a new funding model for HE institutions. In this new model, the research budget is divided among the institutions competitively, according to their research outputs. The research outputs are: competitive research grants (34%), other grants (15%), Ph.D. students (15%), publications (34%), and M.Sc. students (2%). Moreover, the two leading institutions in several areas of science can receive an addition to their research budget of up to 20% (see PBC, 2012). This budgeting model has two problems—neither the amount of the research budget as determined by the PBC nor the division of the budget among the institutions, are necessarily optimal amounts. Indeed, although there are some models suggesting proper contest mechanisms (see Moldovanu & Sela, 2001, 2006; Schweinzer & Segev, 2012), but not in the HE context. Thus, one of the questions that should be asked is whether performance-based competition yields the desired outcome.

In current science policies, competition and output incentives are emphasized as a means of making university systems efficient and productive (Auranen & Nieminen, 2010). Competition (or a contest) is a well-known mechanism for resource allocation. There are many contest-like situations—in the sports world, the labor market, in rent-seeking, and so on. Among the well-known tools used to predict contest outcomes are game theory tools. There are many papers based on game theory that are applicable to contests as a means for analyzing and solving problems in which players expend costly efforts in order to get ahead of one another (Konrad, 2009). Our chapter applies contest theory tools in order to determine if it is better to use performance-based funding (competition) or some form of budget division. There are a limited number of studies that have used game theory to analyze systems of HE. Most of those studies are based on the principal-agent theory to describe the interaction between the government and HE systems (see, for example, Enders et al., 2013; Nisar, 2015).

We propose to use the contest theory framework as a tool for performance-based funding. The interaction between the contestants (universities and colleges or their subordinate departments) and between the responsible authorities, can be modeled as a game. This work focuses on the issue of an additional budget that should be allocated among institutions (universities and colleges) or among departments in one institute. At the first stage, the authorities use allocation mechanisms (a contest or a budget division) and the contestant's abilities (in the case of contests) to determine the budget. The paper finds a proper benchmark that indicates when the contest model or a budget division provides a more favorable outcome, e.g., a higher utility, for the principal (a higher utility).

This chapter presents a game-theory-approach-based model that enables decision-makers to determine the optimal amount of a research budget that should be allotted, and then properly divide this amount among academic units. The academic units in this model are contestants that compete with each other to win the contest; the management of the institution is the contest organizer. The model includes two alternatives—a division of the budget in which the distribution of resources is carried out "fairly" among the contestants, or a competition in which the winner takes all. The study includes a numerical example that demonstrates its applicability.

Contests are economic or social interactions in which two or more players expend costly resources in order to win a prize. The resources expended by players determine their probability of winning a prize (Chowdhury & Sheremeta, 2011). As mentioned, a typical tool to incentivize researchers and academic units is to add budget or other resources such as research equipment or assistants. In any incentive fee method, the principal must determine in advance the incentive amount to be shared (money or resources), and how this amount would be divided among the participants (criteria) in order to maximize its utility.

In this chapter, the contest model is based on a sequential two-stage of a Tullock contest (Tullock, 1980), under complete information. The Tullock model describes a contest where the probability of a contestant winning the contest depends on his effort and the effort of his rivals. The contestant who exerts the greatest effort has the highest probability of winning, but he cannot be certain of actually winning (for more details see Konrad, 2009). Additionally, in our model, we assume complete information, i.e., the abilities of the contestants and the value of the additional budget are publicly known. In the first stage of the contest, the organizer determines the additional budget. The budget size is determined by the ability of the contestants, a form of altruism toward the contestants, and the interest rate that the organizer should pay for the additional budget. In the second stage, the contestants see the size of the budget and determine the amount of effort each is willing to exert.

Chowdhury and Sheremeta (2011) explained why the variations of Tullock's models are widely used. First, a number of studies have provided axiomatic justification for them (Clark & Riss, 1998; Congleton et al., 2008; Skaperdas, 1996). Second, Baye and Hoppe (2003) had identified conditions under which a variety of rent-seeking contests, innovation tournaments, and patent-race games are strategically equivalent to the Tullock contest. In this work, we derive the conditions that determine which mechanism is more profitable to the organizer—a budget division or a contest.

As its main contribution to the literature, this paper proposes a practical application that combines models from the contest theory, the bargaining theory, and the analytical hierarchical process (AHP) that supports higher education budget allocation policy. Moreover, existing literature appears non-existent with regard to determining the size of a Tullock contest prize according to the contestants' abilities, with comparison to a bargaining model. Although there were some works that connected between the effort and the prize, see, for example, Chung (1996), this is an application that is new to budget allocation in HE.

The chapter is organized as follows: Sect. 10.2 presents the background of the study; Sect. 10.3 presents the contest model; Sect. 10.4 presents the bargaining model; Sect. 10.5 compares between contest and budget division solutions; Sect. 10.6 deals with the case of several academic units with identical abilities; Sect. 10.7 is a numerical example; and Sect. 10.8 highlights the main conclusions.

10.2 Background

10.2.1 Budget Allocation Problem in Higher Education

The problem of allocating a budget among HE units can be solved by the use of the linear budget allocation (LBA) model. In the LBA model, the objective function is to maximize the sum of the benefits of the budget allocation, over all the units. Each unit has minimum and maximum requirements regarding its budget needs. Another requirement is that the budget allocation problem must have a feasible solution. In other words, the total budget must be enough to supply the minimum budget needs of all the units. This model can be easily solved by linear programming. One problem of this model is difficulty evaluating the marginal organizational benefit associated with the allocation.

Sinuany-Stern (2014) claimed that this marginal benefit may be estimated subjectively by various single or multi-attribute utility approaches, as proposed by Keeney and Raiffa (1993) or Royes (2004), or by the AHP, as was proposed by Saaty and Vergas (2001). In our proposed model there are also parameters that should be estimated subjectively by experts or by the AHP. Sinuany-Stern (2014) emphasized that there are several requirements needed by a budget allocation model: fairness, effectiveness, and efficiency in the public sector. For nonprofit organizations, fairness is the most important quality desired of a budget allocation model. Sinuany-Stern (2014) proposed a quadratic budget allocation model (QBA), which assumes that the objective function is to minimize the quadratic deviations of the allocations from their bounds. The applicability of this model was demonstrated by an example where a dean of a school of engineering must allocate a budget for several departments in her school. She concluded that the QBA is more fair and effective than the LBA, although the LBA may be more efficient. Thus, the QBA is a better fit for the public sector and for nonprofit organizations, while LBA is more suited for-profit organizations.

10.2.2 Budget Partition and Fairness Index

One of the fairness indexes is $f_A(x) = \left(\sum_{i=1}^{n} x_i\right)^2 / \left(n \sum_{i=1}^{n} x_i^2\right)$, where x_i is the budget allocated to unit i and n is the number of units (Jain et al., 1984). If all the units get identical budgets, the fairness index is 1. When one unit gets the entire budget and all other units get zero, the fairness index is $1/n$. Therefore, $1/n \leq f_A(x) \leq 1$. In general, a fair division is a method of dividing a resource among several parties in such a way that all recipients believe that they have received a fair amount according to some rules of fairness (see, Brams & Taylor, 1996).

Consider a simple example with two academic units, where one unit has two researchers and the other unit has three researchers. Assume that a budget of B$ is planned to be divided fairly between the two units according to the research ability of the two units. If all five researchers have equal abilities, the first unit will get $\frac{2}{5}$B$ and the second unit will get $\frac{3}{5}$B$; but the fairness index between the two units will be 0.9615. Now assume that the two researchers of unit one published a combined total of 10 papers per year. Also, assume that during the same time period the three researchers of unit two published a combined total of 6 papers. In such a case, the marginal publication ability of unit one is $a_1 = 1/10$ and of unit two is $a_2 = 1/6$. A budget division according to the publication capability is $\frac{10}{16}B$ for unit one and $\frac{6}{16}B$ for unit two; but the fairness index between the two units will be 0.9412. From a practical point of view, it can be assumed that $0 < a_i < 1$. The value $a_i = 0$ represents a unit with unlimited ability (infeasible) and $a_i \geq 1$ represents a unit with poor ability (not a candidate for additional budget funding). Sinuany-Stern (2014) stated that an equal budget for all units, or $f_A(x) = 1$, is not always efficient for the owner of the budget. However, as will be shown in this paper, the owner of the budget can ensure more utility by organizing a contest where the winner takes all (see Eq. 10.1), than the utility he can get from a budget division obtained by a bargaining solution (see Eq. 10.15).

10.2.3 Efficiency

Efficiency can be defined as profit (i.e., output minus input), or as the ratio between output and input. In any case, the common aim is maximizing efficiency. It is difficult, and often impossible, to measure efficiency in public sector entities and in nonprofit organizations. This is particularly so because many of their values are often intangible. One method used to measure efficiency in the public sector and in HE institutions is to quantify relative efficiency through the use of data envelopment analysis (DEA) and its variants. For a review of the application of DEA and ranking methods, see Adler et al. (2002) and Hadad and Hanani (2011).

10.2.4 Literature References to Game Theory Applications in Higher Education

There are few papers that directly deal with the application of game theory in HE. Burguillo (2010) presents a method for using game theory tournaments as a way to implement competition-based learning, together with other learning techniques. His goals were to use game theory to help increase motivation learning performance for the students. Burguillo's main contribution is the use of game theory tournaments to develop programming frameworks that can be used to support competition-based learning.

Niklasson (1996) analyzed a 1993 Swedish reform of HE. That reform made changes from central planning to deregulation, privatization, and performance-related funding. He used a model based on game theory to examine the interaction between government and universities, where government and universities are seen as actors in an iterated prisoners' dilemma analysis. Niklasson stated that one problem in his study was to make the universities play against each other, instead of only against the government. Another problem in this and similar models is to ensure socio-economic efficiency.

Nisar (2015) explored the strategy of U.S. President Obama to make colleges more affordable for the middle class. Nisar claimed that "paying for performance" was a core component of Obama's strategy, although most impact assessment studies had shown that such policies have had a limited effect on the performance of these institutions. Most explanations given for this failure have been on the basis of principal-agent theory, resource dependence theory, and neo-institutionalism. Nisar explained the failure of performance-based funding policies in terms of the inherent complexity of the HE system. He used the concept of ecology of games (Long, 1958) and claimed that such games are not based on the rigid assumptions and pay-off structures of classical game theory. Instead, these games are centered on specific policy goals in which various political actors participate, each with different agendas and ideals.

Rothschild and White (1995) developed a model where the contestants are universities that compete for students through price and non-price means. According to their model, some students may be desirable to a university and those students may be the object of special price discounts given by means of scholarships. They specified a simple production process for universities' educational services, based on the Cobb-Douglas production function. The results of the model are a set of prices that would allocate students among universities efficiently. Epple et al. (2006) developed an equilibrium model of the market for HE. They simultaneously predicted student selection into institutions of HE, financial aid, educational expenditures, and educational outcomes. They showed a strict hierarchy of colleges that differ by the educational quality provided to the students. Later, Fu (2014) developed a structural equilibrium model of the HE market. Students, having heterogeneous abilities and preferences, make application decisions subject to uncertainty and application costs. The HE institutions measure student ability and choose tuition and admissions policies to compete for better students.

10.3 The Proposed Contest Model

The proposed contest model is stated as follows: Consider a contest with one principal and several academic units (AUs). The principal might be a governmental or institutional budgeting committee, a president of an academic institute, a dean of faculty, or other groups or individuals serving similar functions with similar responsibilities. The AUs can be academic institutions, academic departments, researchers, and so on. The AUs compete with each other to win extra resources (such as a research budget), where all the AUs are under supervision by the same principle. All the players are risk-neutral and the value of the extra resources is V.

The contest itself will be the execution of an important task for the institution—one that would promote the institution economically and/or would increase its reputation. However, this task will not necessarily produce research outputs for the contestants that will promote them in their academic careers. Such contest tasks might include writing research proposals, developing new curricula, social activities, public relations activities, and other activities that are not directly linked to the academic agenda of the researchers. Therefore, the efforts that the researchers invest in the contest may somehow harm their ongoing academic activities, so their participation in the contest has a price. On the other hand, winning the contest will allow the winning researchers to use the prize money to promote their core research.

The expected utility of the principal is

$$U_c = x_1 + x_2 + \alpha\,(U_1 + U_2) - c(V), \tag{10.1}$$

here:

V—the value of the prize (in monetary units) that the winner in the contest will receive (a decision variable of the principal).

x_i—the efforts (in monetary units) in the contest exerted by the AUs, $i = 1, 2, \ldots, n$ in order to win the contest (decision variables of the AUs). In our case, the cost function of the efforts is linear and given by $g(x_i) = x_i$. Thus, the efforts of the contestants can strictly translate to monetary units.

U_c—the expected utility of the principal (in monetary units).

U_i—the expected utility of the AUs i, $i = 1, 2, \ldots, n$ (in monetary units).

P_i—the probability that AUi will win the contest, $i = 1, 2, \ldots, n$, $\sum_{i=1}^{n} P_i = 1$.

$c(V)$—the cost of the prize to the principal (in monetary units).

Parameters with values that should be estimated:

α—the rate of the expected utility of the contestants that the principal credits to himself.

γ—the coefficient of the cost function of the prize.

a_i—the ability parameter of AU$_i$. A low value of this parameter means a higher ability to produce academic outputs. In other words, it is easier for a contestant with a low a_i value to produce academic outputs. This parameter can be estimated according to previous years' performances.

It is well known that borrowing money has a disadvantage to scale. A larger loan increases the risk taken by the lender, for which he asks a higher rate of interest. The assumption here is that the cost function of the prize, $c(V)$, has a quadratic form that is given by $c(V) = \gamma V^2$ when $\gamma > 0$. This proposed form was developed by Baker et al. (1994) and it is based on the concept of increasing the marginal cost of incentives, which is a common assumption in financial markets.

The utility function of the principal includes a portion of the AUs' utility. Given that the extra resources will help the research projects succeed, the principal has an incentive to allot the extra resources to the AUs. The value of parameter α describes the rate of the expected utility of the AUs that the principal credits to himself. In other words, $\alpha \to 0$, no credit, $\alpha \to \infty$, very high credit.

The expected utility functions of the AUs are based on a variation of the Tullock contest, given by

$$U_1^c = VP_1 - a_1 x_1, \tag{10.2}$$

$$U_2^c = VP_2 - a_2 x_2, \tag{10.3}$$

where $0 < a_i < 1$ is the ability factor of AU $i = 1, 2$ (a small value of a_i means high ability).

The probabilities are given by

$$P_1 = \frac{x_1}{x_1+x_2},$$
$$P_2 = \frac{x_2}{x_1+x_2}.$$

The stages of the game are as follows: In the first stage, the principal chooses the value of the extra resources to be allotted (V), in order to maximize his expected utility. In the second stage, the AUs see the value of the extra resources and determine the efforts they want to exert in the contest.

In order to analyze the subgame perfect equilibrium of the contest, a backward induction is used beginning with the second stage. The second stage is a simple asymmetric Tullock contest with a well-known solution that maximizes the problems shown in (10.2) and (10.3) (see, for example, Nti (1999), Konrad (2009)). Thus, the efforts in the contest are

$$x_1 = \frac{a_2}{(a_1 + a_2)^2} V, \tag{10.4}$$

$$x_2 = \frac{a_1}{(a_1 + a_2)^2} V. \tag{10.5}$$

Substituting (10.4 and 10.5) in (10.2 and 10.3) yields

$$U_1^c = \frac{a_2^2}{(a_1 + a_2)^2} V, \tag{10.6}$$

$$U_2^c = \frac{a_1^2}{(a_1 + a_2)^2} V. \tag{10.7}$$

Substituting (10.4), (10.5), (10.6), and (10.7) into (10.1) yields

$$U_c = \frac{a_2}{(a_1+a_2)^2} V + \frac{a_1}{(a_1+a_2)^2} V + \alpha \left(\frac{a_2^2}{(a_1+a_2)^2} V + \frac{a_1^2}{(a_1+a_2)^2} V \right) - \gamma V^2.$$

Thus, the maximization problem of the principal is

$$\max_V U_c = \max_V \left(\frac{V}{(a_1 + a_2)} + \frac{a_2^2 + a_1^2}{(a_1 + a_2)^2} \alpha V - \gamma V^2 \right) \tag{10.8}$$

Differentiating (10.8) with respect to V yields

$$\frac{\partial U_c}{\partial V} = \frac{1}{(a_1 + a_2)} + \frac{a_2^2 + a_1^2}{(a_1 + a_2)^2} \alpha - 2\gamma V = 0$$

Rearranging the derivative

$$V^* = \frac{1}{2\gamma} \left(\frac{1}{(a_1 + a_2)} + \frac{a_2^2 + a_1^2}{(a_1 + a_2)^2} \alpha \right). \tag{10.9}$$

The second derivative is $\frac{\partial^2 U_c}{\partial V^2} = -2\gamma < 0$. Namely, the second-order conditions for local maximum are satisfied.

Substituting (10.9) in (10.8) yields

$$U_c = \frac{1}{4\gamma} \left(\frac{1}{(a_1 + a_2)} + \frac{a_2^2 + a_1^2}{(a_1 + a_2)^2} \alpha \right)^2. \tag{10.10}$$

Then, substituting (10.9) in (10.4, 10.5, 10.6, and 10.7) will yield the contestant efforts and the utilities.

10.4 The Bargaining Model for Budget Division

Now consider a case where the principal allows the AUs to engage in bargaining with each other for the extra resources; the extra resources between the AUs will be allotted by the principal according to the agreement reached by the AUs. In a case of disagreement between the AUs that prevents a budget division (the bargaining model solution), the contest solution will be used.

The bargaining solution will yield a different utility function to the principal because in such case the utility does not depend on the efforts of the AUs. In any event, in the bargaining process, the principal enjoys a portion of the utilities of the AUs. In some cases, a bargaining solution might be a better solution for the principal than the contest solution, as will be presented later. The utility function of the principal in the case of bargaining is

$$U_d = \alpha\left(U_1 + U_2\right) - \gamma V_d^2. \tag{10.11}$$

The value V of the extra resources is determined according to this bargaining solution. The proposed division rule between the AUs is $0 \le \theta \le 1$ and accordingly, the AUs' utilities are

$$U_1^b = V_d\theta, \tag{10.12}$$

$$U_2^b = V_d\left(1 - \theta\right). \tag{10.13}$$

This type of division rule is common in many bargaining solutions (see, for example, Anbarci et al., 2002, Skaperdas, 2006, the Nash bargaining solution, or the Kalai–Smorodinsky solution). For example, in a Nash bargaining solution θ is chosen to maximize the following product:

$$\max_{\theta}\left(U_1^d - U_1^c\right)\left(U_2^d - U_2^c\right). \tag{10.14}$$

From (10.11) it is easy to see that in this case, the optimal value of the extra resources to be allotted is $V_d^* = \left(\frac{\alpha}{2\gamma}\right)$and the principal's utility is given by

$$U_d = \frac{\alpha^2}{4\gamma}. \tag{10.15}$$

10.5 Contest Versus Budget Division

This section includes a comparison between the two mechanisms (a contest and a budget division), in order to select the mechanism that will yield a higher utility for the principal. It is well known that in the case of a linear cost function in a contest, it is not a good policy to divide the prize and establish two prizes (see, Moldovanu & Sela, 2001; Schweinzer & Segev, 2012). Furthermore, in a case with two contestants, the second prize is considered by the contestants as a consolation prize. Generally, in a divided prize case, the effort of the contestants will be exerted according to the difference between the main prize and the consolation prize (see, for example, Szymanski & Valletti, 2005).

The following two propositions derive conditions under which one mechanism (a contest or a budget division) is more profitable for the principal.

Proposition 10.1 There exists α^* *such that for all* $\alpha < \alpha^*$*, a contest is more profitable for the principal than a budget division, and* vice versa.

Proof: Taking the difference between (10.10) and (10.15) we get

$$U_c - U_d = \frac{1}{4\gamma}\left[\left(\frac{1}{(a_1 + a_2)} + \frac{a_2^2 + a_1^2}{(a_1 + a_2)^2}\alpha\right)^2 - \alpha^2\right].$$

Notice that

$$\frac{\partial^2 (U_c - U_d)}{\partial \alpha^2} = \frac{1}{2\gamma}\left[\left(\frac{a_2^2 + a_1^2}{(a_1 + a_2)^2}\right)^2 - 1\right].$$

Because $0 \le \frac{a_2^2+a_1^2}{(a_1+a_2)^2} \le 1$ we get $\frac{\partial^2(U_c-U_d)}{\partial\alpha^2} < 0$.

Because $U_c - U_d|_{\alpha=0} > 0, U_c - U_d|_{\alpha\to\infty} < 0$, and $\left.\frac{\partial(U_c-U_d)}{\partial\alpha}\right|_{\alpha=0} = \frac{1}{2\gamma}\left(\frac{a_2^2+a_1^2}{(a_1+a_2)^4}\right) > 0$, there exists an α^* that fulfils the condition that $U_c - U_d|_{\alpha=\alpha^*} = 0$, such that for $\alpha > \alpha^*$, $U_c - U_d < 0$ and for $\alpha < \alpha^*$, $U_c - U_d > 0$. That yields the result of Proposition 10.1.□

The intuition behind the results is as follows: for a small α, the authorities prefer a contest because their cost for the effort transferred from the academic units is low. Once $\alpha$is large, the cost borne by the academic unit transferred to the authorities' payoff is too high to conduct a contest.

10.6 The Case of Several AUs with Identical Abilities

This section considers a case with n AUs that have identical abilities ($a_1 = a_2 = \ldots = a_n = a$). For AUs with identical abilities, a budget division is made simply by dividing the resource equally among the AUs, $\left(\frac{V_d}{n}\right)$. The principal's utility in this case is $U_d = \alpha\left(\sum_{i=1}^{n} U_i\right) - \gamma V_d^2 = \alpha n\frac{V_d}{n} - \gamma V_d^2 = \alpha V_d - \gamma V_d^2$. Thus, result (10.15) also holds for this case and

$$U_d^n = \frac{\alpha^2}{4\gamma}. \tag{10.16}$$

In a contest setup, the principal's utility is

$$U_c^n = \sum_{i=1}^{n} x_i + \alpha \left(\sum_{i=1}^{n} U_i \right) - \gamma V^2. \tag{10.17}$$

Following (10.2) and (10.3), the utilities of AU i, $i = 1, \ldots, n$ can be rewritten as:

$$U_i = V P_i - a x_i, \tag{10.18}$$

where $P_i = \frac{x_i}{\sum_{i=1}^{n} x_i}$.

By applying the backward induction approach as used in the previous section, the solution of (10.18) is the well-known symmetric equilibrium of a Tullock contest (see, for example, Konrad, 2009), which is given by:

$$x_i = \frac{n-1}{n^2} \frac{V}{a} \quad i = 1, \ldots, n, \tag{10.19}$$

$$\mathrm{U}_i = \frac{V}{n^2} \quad i = 1, \ldots, n. \tag{10.20}$$

Substituting (10.20 and 10.19) in (10.17) yields:

$$U_c^n = \frac{n-1}{n} \frac{V}{a} + \frac{\alpha}{n} V - \gamma V^2. \tag{10.21}$$

Differentiating (10.21) with respect to V yields: $\frac{\partial U_c^n}{\partial V} = \left(\frac{n-1}{an} + \frac{\alpha}{n} \right) - 2\gamma V = 0.$ By rearranging the derivative:

$$V^* = \frac{1}{2\gamma} \left(\frac{n-1}{an} + \frac{\alpha}{n} \right), \tag{10.22}$$

and the second derivative, $\frac{\partial^2 U_c}{\partial V^2} = -2\gamma < 0$. Thus, the second order condition for the local maximum is satisfied. Substituting (10.22) in (10.21) yields:

$$U_c^n = \frac{1}{4\gamma} \left(\frac{n-1}{an} + \frac{\alpha}{n} \right)^2. \tag{10.23}$$

The next proposition addresses a comparison between a contest and a budget division. As mentioned before, dividing the prize in a case of linear cost function like in Tullock contest is not optimal (Schweinzer & Segev, 2012). Thus, we focus on a comparison between the cases where the winner takes all (a contest) and a budget division.

Proposition 10.2 There is α^* such that for all $\alpha < \alpha^*$, a contest is more profitable for the principal than a budget division, and vice versa.

Proof: In a manner similar to that of Proposition 10.1, $\frac{\partial^2(U_c^n - U_d^n)}{\partial\alpha^2} = \frac{1}{2\gamma}\left(\frac{1}{n^2} - 1\right) < 0$. Because $U_c^n - U_d^n\big|_{\alpha=0} > 0$, $U_c^n - U_d^n\big|_{\alpha\to\infty} < 0$ and $\frac{\partial(U_c^n - U_d^n)}{\partial\alpha}\Big|_{\alpha=0} = \frac{1}{2\gamma}\left(\frac{n-1}{an^2}\right) > 0$, we get that for all $\alpha < \alpha^*$, $U_c^n - U_d^n > 0$ and for $\alpha > \alpha^*$, the inequality is reversed.□

10.7 A Numerical Example

The president of an academic institution in Israel is interested in providing research funds to the academic departments. These funds are intended to be used in order to promote the quality of the research and the scope of publications, to increase the academic reputation of the institution, and to produce economic opportunities.

The budget planned for this purpose is NIS 100,000 (V_1) (about $30,000). Taking into account the overheads related to this budget (15%), the effective cost of this amount to the institute is NIS 115,000 (V_2). From these two values and the formula $c(V) = \gamma V^2$, the value of parameter γ can be calculated as follows: $\gamma = \frac{V_2}{V_1^2} = \frac{115}{100^2} = 0.0115$.

The research budget will be given to one of two academic departments, department A and department B, on a competitive basis. Department A has 15 academic staff members and department B has 8 academic staff members. The benefit gained by the winning department would directly benefit the institution itself. It is estimated that the benefit to the institution is 20% higher than the benefit gained by the winning department. Therefore, the value of α is determined to be$\alpha = 1.2$.

In order to estimate the value of the coefficient of the marginal research capability(a_i) the following four criteria were selected:

P—Peer-reviewed papers
W—Winning research proposals
C—Participation in academic conferences
S—Supervision of graduate students

In order to determine the relative importance of each criterion, the AHP methodology (Satty, 1980) was used. The weight of each criterion, as presented in Table 10.2, is based on the principal eigenvector of a pairwise comparison matrix, as presented in Table 10.1. If, for example, the value between *P* and *C* in the comparison matrix (Table 10.1) is 7, it means that from the point of view of the decision-maker, one peer-reviewed paper equals seven participations in academic conferences.

Table 10.1 Pairwise comparison matrix

	P	*W*	*C*	*S*
P	1	1/3	7	3
W	3	1	9	3
C	1/7	1/9	1	1/3
S	1/3	1/3	3	1

Table 10.2 Weights of the criteria

Category	Priority (%)	Rank
P	28.7	2
W	53.5	1
C	4.6	4
S	13.2	3

Table 10.3 Research outputs of the two departments

Outputs	Weights (%)	Department A	Department B
Peer-reviewed papers	28.7	32	25
Winning research proposals	53.5	6	4
Participation in academic conferences	4.6	19	15
Supervision of graduate students	13.2	8	11

In the AHP the numeric values are derived from the subjective preferences of the decision-makers. Therefore, some inconsistencies in the matrix of judgments may occur. Saaty (2012) showed that a consistency ratio (CR) of 10% or less is acceptable to continue using the AHP analysis. If the consistency ratio is greater than 10%, it becomes necessary to revise the comparison values of the judgments in order to obtain more consistency. In our case, the consistency ratio is CR = 4.6% (less than 10%), which means that the decision-maker is consistent. The weights of the four criteria based on this matrix (Table 10.1) are presented in Table 10.2.

The research outputs of the two departments during the previous year are presented in Table 10.3.

These weights can be used to convert the four output types into a single output type. This step is needed in order to calculate the marginal research ability, a_i. In this case, all the outputs will be converted into "article equivalents." This output (articles) was selected as a reference because the management of the institution defined as a standard the requirement that each academic member produce 1.5 articles per year. The ratio between the weights of each output to the weight of the output "articles" is the equivalent of one unit of specific output per article. For example, one winning research proposal is equivalent to $\frac{53.5\%}{28.70\%} = 1.8641$ articles. Table 10.4 shows that department "A" produced outputs that were equivalent to 49.91 articles, and department "B" produced outputs that equivalent to 39.92 articles.

As stated, the standard research outputs for each academic member per year is equivalent to 1.5 articles. The ratio between the actual weighted outputs and the standard outputs reflects the efficiency of the departments. The efficiency

Table 10.4 Article equivalent research outputs of the two departments

Outputs	Equivalent to one article	Department A outputs (articles equivalent)	Department B outputs (articles equivalent)
Peer-reviewed papers	1.0000	32.00	25.00
Winning research proposals	1.8641	11.18	7.46
Participation in academic conferences	0.1603	3.05	2.40
Supervision of graduate students	0.4599	3.68	5.06
Total articles equivalent		49.91	39.92

of department "A," which has 15 academic members, is $\frac{49.91}{15\times1.5} = 2.22$. The department's research output is 122% higher than the standard output. Therefore, its ability parameter is $a_A = \frac{1}{2.22} = 0.45$. When calculated in a similar manner, the ability parameter of department "B" is $a_B = 0.30$.

Substituting the values in the model (10.9) yields $V* = 85.101$. In other words, the amount that should be allocated as a prize to the winning department in the competition (which lasted for 1 year of research) is NIS 85,101. Because not all the budget is being allocated to the prize, the remainder will be used by the institution to promote research goals in other ways. The net expected utility of the institution itself from the competition is $U_c = 83.286$. In this contest model, one department gets all the budget $V* = 85.101$ and the other department gets zero. Therefore, the fairness index is 0.5.

The probability of department "A" to win the contest is $p_A = \frac{a_B}{a_A+a_B} = \frac{0.3}{0.3+0.45} = 0.4$,while the probability of department "B" to win the contest is $p_B = \frac{a_A}{a_A+a_B} = 0.6$. It is clear that if the parties want to increase their chance of winning in any future contest they must improve their abilities in the long run.

The optimal budget of the bargaining prize in this numerical example is $V_d^* = \frac{\alpha}{2\gamma} = \frac{1.2}{2\times0.0115} = 52.17$. The division of this amount, $V_d^* = 52.17$, between the two departments can be done according to the Nash bargaining solution or by any similar method. Ultimately, the net expected utility of the institution itself from a budget division is $U_d = 24.00$, for any division. If the division of the amount $V_d^* = 52.17$is done according to the "research outputs" of each department as presented in Table 10.4, then $V_A = V_d^* \times 49.91/\,(49.91 + 39.92) = 28.99$ and $V_B = V_d^* \times 39.92/\,(49.91 + 39.92) = 23.18$. The fairness index for this division is $f_A(x) = 0.9875$. Note that both solutions, the contest prize and the bargaining budget, are less than the budget that was planned initially by the president of the institution. The residual budget can be used for other research goals.

10.8 Conclusions

Academic institutions must deal with the problem of research budget size and how it should be divided among subordinate academic units. Allocation of an appropriate research budget would improve and increase research outputs. More high-quality research outputs will improve the academic reputation of the institution and its ability to raise higher budgets and recruit students. This chapter proposed a unique competition model based on the Tullock contest, which enables decision-makers in HE institutions to determine the optimal research budget and its distribution among academic units: researchers, institutions, or departments.

The chapter includes a comparison between two mechanisms for determining and allocating a budget for a prize, a contest or a budget division. The issue of which mechanism is better was examined from the point of view of the organizer. The conditions when a contest is preferable and when a division is preferable to the organizer were exactly defined. It was shown that a budget division is better for the organizer than a contest, if the utilities of the contestants are very important for the organizer, i.e., the contestants' utilities are a significant part of the organizer's utility. Otherwise, a contest is preferred. The model is expanded to unlimited contestants where the participants have the same ability.

We used a method based on AHP methodology for estimating the research abilities of the academic units in the institution. We followed this methodology in order to determine research ability, a_i, and thus to identify the two academic units with the highest abilities in the institution; those were the units that would participate in the contest. The research budget was determined according to the abilities of the participants in the contest, the cost of raising the needed budget, and the benefit of the contest organizer.

The model can be used by managers in various applications in which there is a requirement to allocate a budget on a competitive basis. For example, research and development budgets where the contestants are universities and academic units, cultural budgets for institutions where the contestants are theaters and concert houses, and sports budgets where the contestants are athletes and teams.

Future research may take several directions:

- Solving a contest model with more than two contestants, where each participant has a different ability. This problem does not yet have an analytically close solution.
- In a contest with N identical participants, it is easy to see that engaging more participants yields a higher utility to the organizer. Our conjecture is that this is also true for a contest with N participants, where each participant has a different ability. This issue should be explored.
- Extension of the proposed model to a case with incomplete information and to an all-pay contest model where the contestant with the highest effort wins the contest with a probability 1 result. (In a Tullock contest, the contestant with the highest effort has only the highest probability of winning).

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Chapter 11
A Fast Threshold Acceptance Algorithm for the Examination Timetabling Problem

Nuno Leite, Fernando Melício, and Agostinho C. Rosa

Abstract In this chapter, an accelerated variant of the *threshold acceptance* (TA) metaheuristic, named FastTA, is proposed for solving the examination timetabling problem. FastTA executes a lower number of evaluations compared to TA while not worsening the solution cost in a significant way. Each exam selected for scheduling is only moved if that exam had any accepted moves in the immediately preceding *threshold bin*; otherwise, the exam is fixed and is not evaluated anymore. If an exam had zero accepted movements in the preceding threshold bin, it is likely to have few or zero accepted movements in the future, as it is becoming crystallised. The FastTA and TA were tested on the Toronto and Second International Timetabling Competition benchmark (ITC 2007) sets. Compared to TA, the FastTA uses 38% and 22% less evaluations, on average, on the Toronto and ITC 2007 sets, respectively. On the ITC 2007 set, the FastTA is competitive with TA attaining the best average solution cost value in four out of twelve instances while requiring less time to execute. Compared with the state-of-the-art approaches, the FastTA is able

N. Leite (✉)
Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Lisboa, Portugal

LARSyS—Laboratory for Robotics and Systems in Engineering and Science, Universidade de Lisboa, Lisboa, Portugal
e-mail: nleite@cc.isel.ipl.pt

F. Melício
Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Lisboa, Portugal

LARSyS—Laboratory for Robotics and Systems in Engineering and Science, Universidade de Lisboa, Lisboa, Portugal
e-mail: fmelicio@laseeb.org

A. C. Rosa
Department of Bioengineering/Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

LARSyS—Laboratory for Robotics and Systems in Engineering and Science, Universidade de Lisboa, Lisboa, Portugal
e-mail: acrosa@laseeb.org

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to achieve competitive results. The main contribution/value of this chapter is the proposal of a new acceptance criterion for the TA metaheuristic, which leads to a significantly faster variant (FastTA), and its application to solve public examination timetabling benchmark sets.

Keywords Examination timetabling · Hybrid algorithm · ITC 2007 benchmark set · Local search · Threshold acceptance · Timetabling · Toronto benchmark set

11.1 Introduction

Many companies and organisations deal with timetabling problems, having to build various types of timetables on a regular basis. This is the case of transportation and railway companies, bus/metro service, sport federations, hospitals, universities, among others. The timetabling problem is also solved generally by companies that need to schedule personnel or resources for a given task, e.g., work shifts, or supermarket companies that need to distribute and deliver, themselves, the products to their online customers. Since timetabling is a combinatorial problem, dealing with it in medium- and large-size companies is a very complex task. Therefore, automatic solvers are required by companies' decision makers in order to solve their timetabling tasks.

Timetabling problems involve fixing a time for sets of triples (*events*, *resources*, *space*), satisfying a given set of hard and soft constraints. Events can comprise lectures, examinations, surgeries, sport events, or trips. Resources can include teachers, nurses and medical staff, sports referees, or vehicles. Space can be classrooms, hospital rooms, or sport fields.

In this chapter, the examination timetabling problem (ETP) (Qu et al., 2009) is solved. This problem consists in scheduling exams to rooms and time slots, trying to space out enrolled students as much as possible, as well as satisfying other constraints. Two published benchmark sets, the *Toronto* (Carter et al., 1996) (also known as Carter's datasets) and the *Second International Timetabling Competition (ITC 2007)* (McCollum et al., 2012), comprise the standard sets mainly used by researchers in this area.

The ETP is a NP-complete decision problem (de Werra, 1985, 1997). Methods applied to solve this problem include operations research approaches (e.g., mathematical programming), for relatively small-size problem instances, and approximate methods (artificial intelligence (Schaerf, 1999) methods, metaheuristics (Qu et al., 2009), and constraint programming approaches).

11.1.1 Related Work

The first studies involving the examination timetabling problem include the seminal works by Broder (1964) and Cole (1964), which are the first works that try to solve the problem using a computer program. Carter and Laporte (1996) and Schaerf (1999) review recent approaches employed to solve the ETP. In Welsh and Powell (1967), a relation between the related problems of graph colouring and timetabling is studied. In Carter (1986), the authors employ various graph colouring heuristics to solve the ETP. One of the most successful graph colouring is the *saturation degree* heuristic proposed by Brélaz (1979). In Cheong et al. (2009), the authors study the application of four graph colouring heuristics to the ETP, namely *largest degree*, *colour degree*, *saturation degree*, and *extended saturation degree*. They conclude that the saturation degree heuristic was among the two best heuristics.

Mathematical programming approaches for solving the ETP were proposed in the research literature. In a recent work, Woumans et al. (2016) propose a column generation approach for solving the examination timetabling problem. The authors apply two mathematical models to solve the ETP at KU Leuven campus Brussels (Belgium), for the business engineering degree program, and apply the models to the `sta83` and `yor83` instances of the Toronto benchmark set from the literature. However, they used a different formulation of the Toronto set in which an exam is allowed to be scheduled more than once in the timetabling. The reported results are good on smaller datasets such as the ETP at KU Leuven. The results were also good for the Toronto dataset (multiple exam formulation) using one of the proposed models, obtaining new upper bounds on the Toronto set's `sta83` and `yor83` instances. However, on larger datasets such as the `yor83` instance, the second model was not able to obtain a feasible solution within the time limit of 400 hours.

Local search approaches, such as *simulated annealing* (SA) (Kirkpatrick et al., 1983), are within the most used metaheuristics used to solve timetabling problems. The use of SA to timetabling dates back to the 1990s, with the pioneer works of Dowsland (1990) and Abramson (1991). In a later investigation, Thompson and Dowsland (1996) use SA to solve a variant of the ETP (a multi-objective formulation of the ETP). In Thompson and Dowsland (1998), the same authors propose an approach based on SA for solving examination timetabling problems. The authors employ and compare three neighbourhoods (standard, Kempe chains, and S-Chains). In their experiments, the authors conclude that the Kempe chains neighbourhood, a concept extracted from the graph theory and used also on graph colouring problems, is the most effective one. In the literature, SA-based approaches were also used to solve other types of educational timetabling problems (school and course timetabling), such as the works of Melício et al. (2000), Melício et al. (2004), Zhang et al. (2010), and Bellio et al. (2016). More recently, the SA was used to solve the ITC 2007 problem formulation (Battistutta et al., 2017). In their work, the initial solution is generated in a random fashion and could be infeasible. Non-feasible states are penalised by the algorithm. The authors employ a statistically principled experimental analysis with the goal of understanding the effect of parameter selection on the algorithm performance. After this, the algorithm parameters are set using a feature-based parameter tuning, which is able to achieve a good generalisation on unseen instances. The study concludes that the standard SA, when properly tuned, is able to solve the ITC 2007 problem effectively.

June et al. (2019) propose the application of *constraint programming* and *simulated annealing* and use their method to produce the exam timetable of Universiti Malaysia Sabah Labuan International Campus (UMSLIC).

Li et al. (2015) propose a search framework for exam timetabling problems based on evolutionary ruin and stochastic rebuild and apply it to solve the Toronto benchmark set.

The ITC 2007 participants have proposed methods that range from hybrid local search (Müller, 2009), *greedy randomised adaptive search procedure* (GRASP) combined with other local search metaheuristics (Gogos et al., 2008), constraint programming solver hybridised with *tabu search* and *iterated local search* (Atsuta et al.—2008 (McCollum et al., 2010)), *tabu search* approach (De Smet—2008 (McCollum et al., 2010)), and nature-inspired heuristic approach based on cell biology (Pillay—2008 (McCollum et al., 2010)).

Other works on the ITC 2007 examination timetabling track comprise methods ranging from population-based metaheuristics, such as *bee colony optimisation* (Alzaqebah & Abdullah, 2014, 2015) and *cellular memetic algorithm* (Leite et al., 2018), *hill-climbing* variants (Bykov & Petrovic, 2013), *great deluge* local search (Hamilton-Bryce et al., 2013; McCollum et al., 2009), GRASP (Gogos et al., 2012), to *hyper-heuristics* (Demeester et al., 2012; Özcan et al., 2012; Burke et al., 2014; Sabar et al., 2015). Bykov and Petrovic (2016) present a new single-parameter local search heuristic named *step counting hill-climbing* algorithm (SCHC). The algorithm is applied to the ITC 2007 examination timetabling track. Leite et al. (2019) propose an accelerated variant of SA, named FastSA, that is able to reduce the number of evaluations as compared to SA. The FastSA was tested on the ITC 2007 benchmark set requiring 17% less evaluations, on average, compared with SA, and attaining a new upper bound on one instance.

Some surveys on the field of educational timetabling were published recently. Qu et al. (2009) present a detailed survey of algorithmic strategies applied to the ETP. Kristiansen and Stidsen (2013), Johnes (2015), and Teoh et al. (2015) survey the application of operations research and metaheuristic approaches to academic scheduling problems. Gashgari et al. (2018) present a recent survey on exam scheduling techniques. Bettinelli et al. (2015) present an overview of curriculum-based course timetabling. Pillay (2016) presents a review of hyper-heuristics for educational timetabling.

Metaheuristics' components were recently studied in the literature. In Dowsland and Thompson (2012), the authors study the several components of simulated annealing and its variations. In Santini et al. (2018), the authors investigate the move acceptance criterion component of *adaptive large neighbourhood search* (ALNS) and compare a range of alternatives. Among the best variants, the authors find versions of criteria based on *simulated annealing*, *threshold acceptance*, and *record-to-record travel* algorithms.

Table 11.22, in the Appendix, presents the main characteristics of recent methodologies applied to solve educational timetabling problems for Higher Education (HE).

11.1.2 This Chapter's Contribution

In this chapter, an approach based on the *threshold acceptance* (TA) Dueck and Scheuer (1990) local search algorithm is proposed for solving the examination timetabling problem. Threshold acceptance is a metaheuristic method that belongs to the family of simulated annealing. TA has been applied in several areas ranging from operations research to optimisation in statistics and econometrics Winker (2001).

The proposed method comprises two phases, a construction phase and an optimisation phase. We extend the study made earlier on the SA in Leite et al. (2019) and study how the TA could be accelerated, similarly to what is done in Leite et al. (2019). The proposed approach, named *fast threshold acceptance* (FastTA), is tested on the Toronto and ITC 2007 benchmark sets and compared with the state-of-the-art approaches.

The main contribution/value of this chapter is the proposal of a new acceptance criterion for the TA metaheuristic, which leads to a significantly faster variant (FastTA), and its application to solve public examination timetabling benchmark sets.

The remaining sections of this chapter are organised as follows. In Sect. 11.2, the notations and abbreviations used in this chapter are defined. Section 11.3 describes the uncapacitated Toronto and capacitated ITC 2007 problem instances. Section 11.4 presents the proposed approach based on the threshold acceptance metaheuristic for solving the examination timetabling problem. Section 11.5 reports the experimental results on the Toronto and ITC 2007 benchmark sets and compares FastTA's results with the ones in the literature. Section 11.6 presents concluding remarks and future work.

11.2 Notations and Abbreviations

For the convenience of readers, we collect below the various notations and abbreviations employed in the text.

e_i	Exam identifier
E	A set of exams
t_k	Timeslot identifier

P	A set of timeslots (or periods)
r_l	Room identifier
R	A set of rooms
$C = (c_{ij})_{\lvert E\rvert \times \lvert E\rvert}$	Symmetric matrix of size $\lvert E\rvert$ (called the *conflict matrix*) where each element, denoted by c_{ij} $(i, j \in \{1, \ldots, \lvert E\rvert\})$, represents the number of students attending both exams i and j
M	Total number of students
$\delta_{i,j}$	The Kronecker delta function
f_c	Solution cost
σ	Standard deviation
s	Solution identifier
$N(s)$	Neighbourhood of solution s
Q	Threshold value in *threshold acceptance* algorithm
r	Cooling schedule rate in *threshold acceptance* algorithm
k	Number of iterations performed at a given threshold in *threshold acceptance* algorithm
α	Alpha level or significance level
p	p-value

11.3 Examination Timetabling Problems

In this section, the Toronto and ITC 2007 benchmark sets are described.

11.3.1 Uncapacitated Toronto Dataset

The Toronto benchmark set is a well-known set used in examination timetabling research. It is an uncapacitated dataset, meaning that no rooms are considered in its specification. The formulation provided here was adapted from Abdullah et al. (2009) and Burke et al. (2004). The following terms are defined:

- $E = \{e_1, \ldots, e_n\}$ is the set of exams.
- $P = \{p_1, \ldots, p_k\}$ is the set of time slots (or periods).
- $C = (c_{ij})_{\lvert E\rvert \times \lvert E\rvert}$ (called the *conflict matrix*) is a symmetric matrix of size $\lvert E\rvert$ where each element, denoted by c_{ij} $(i, j \in \{1, \ldots, \lvert E\rvert\})$, represents the number of students enrolled simultaneously in exams i and j.
- M denotes the total number of students.
- t_k $(t_k \in P)$ indicates the time slot where exam e_k $(e_k \in E)$ is scheduled.

The Toronto problem formulation introduces a single soft constraint that disallows students to take two exams in near periods (periods that differ from one to five time slots). This constraint is denoted by the f_c function, specified in (11.1). The problem is formulated as follows:

$$\text{minimise} \quad f_c = \frac{1}{M} \cdot \sum_{i=1}^{|E|-1} \sum_{j=i+1}^{|E|} c_{ij} \cdot \text{prox}(i, j), \tag{11.1}$$

where

$$\text{prox}(i, j) = \begin{cases} 2^{5-|t_i - t_j|}, \ if \ \ 1 \le |t_i - t_j| \le 5 \\ 0, \text{otherwise} \end{cases} \tag{11.2}$$

subject to

$$\sum_{i=1}^{|E|-1} \sum_{j=i+1}^{|E|} c_{ij} \cdot \delta_{t_i, t_j} = 0, \quad \delta_{t_i, t_j} = \begin{cases} 0, \ t_i \ne t_j \\ 1, \ t_i = t_j \end{cases} . \tag{11.3}$$

Function prox(i, j) in (11.2) specifies how the penalty is calculated when exams e_i and e_j are scheduled in time slots t_i and t_j, respectively. The resulting penalty is 16, 8, 4, 2, and 1, for exams sitting one, two, three, four, and five time slots apart, respectively. For exams that sit more than five time slots apart, there is no penalty. Equation (11.3) denotes the unique hard constraint, which forbids conflicts between two or more exams scheduled in a given time slot.

Table 11.1 presents the characteristics of the uncapacitated Toronto benchmark set (version I). In Table 11.1, the conflict matrix density is the ratio of the number of non-zero elements in the conflict matrix and the total number of elements. The Toronto dataset is available at ftp://ftp.mie.utoronto.ca/pub/carter/testprob.

Table 11.1 Specifications of the uncapacitated Toronto benchmark set (version I)

Dataset	# Exams	# Students	# Enrolments	Conflict matrix density	# Time slots
car91	682	16, 925	56, 877	0.13	35
car92	543	18, 419	55, 522	0.14	32
ear83	190	1125	8109	0.27	24
hec92	81	2823	10, 632	0.42	18
kfu93	461	5349	25, 113	0.06	20
lse91	381	2726	10, 918	0.06	18
pur93	2419	30, 029	120, 681	0.03	42
rye93	486	11, 483	45, 051	0.08	23
sta83	139	611	5751	0.14	13
tre92	261	4360	14, 901	0.18	23
uta92	622	21, 266	58, 979	0.13	35
ute92	184	2749	11, 793	0.08	10
yor83	181	941	6034	0.29	21

11.3.2 The ITC 2007 Dataset

The ITC 2007 benchmark set (International Timetabling Competition, 2007) consists of three tracks, each one related to a type of educational timetabling problem:

- Track 1—examination timetabling
- Track 2—post-enrolment-based course timetabling
- Track 3—curriculum-based course timetabling

The examination timetabling track, which is focused in this chapter, specifies instances with characteristics and constraint types that are similar to real-world instances found in practice. It is comprised of 12 instances whose features are described in Table 11.2. The ITC 2007 formulation extends the Toronto formulation by adding new kinds of hard and soft constraints.

The ITC 2007 hard constraints are the following (McCollum et al., 2012):

- *No Conflicts*—Exams having enrolled students in common (conflicting exams) cannot be scheduled in the same time slot.
- *Room Occupancy*—The room capacity cannot be exceeded for each room and time slot.
- *Period Utilisation*—For each exam scheduled in a time slot, the exam duration cannot exceed the time available in that period.
- *Period Related*—Time-ordering requirements exist for pairs (e_1, e_2) of exams, which are specified by the following constraints:
  - *After Constraint*—e_1 must take place strictly after e_2.
  - *Exam Coincidence*—e_1 must take place at the same time as that of e_2.
  - *Period Exclusion*—e_1 must not take place at the same time as that of e_2.

Table 11.2 Basic properties of the instances of the ITC 2007s examination timetabling track

Dataset	Density	Exams	Students	Periods	Rooms	Period HC	Room HC
Exam_1	0.05	607	7891	54	7	12	0
Exam_2	0.01	870	12, 743	40	49	12	2
Exam_3	0.03	934	16, 439	36	48	170	15
Exam_4	0.15	273	5045	21	1	40	0
Exam_5	0.009	1018	9253	42	3	27	0
Exam_6	0.06	242	7909	16	8	23	0
Exam_7	0.02	1096	14, 676	80	15	28	0
Exam_8	0.05	598	7718	80	8	20	1
Exam_9	0.08	169	655	25	3	10	0
Exam_10	0.05	214	1577	32	48	58	0
Exam_11	0.03	934	16, 439	26	40	170	15
Exam_12	0.18	78	1653	12	50	9	7

Density is the conflict density. HC refers to the numbers of hard constraints

- *Room Related*—An additional room requirement was defined:
  - *Room Exclusive*—A given exam e_1 must take place in a given room, with exclusive use.

As an additional requirement, the solution must be complete, i.e., all exams have to be scheduled in the timetable. Exams must also not be allocated in more than one period or room. A solution is said to be feasible if it satisfies the set of hard constraints.

The following set of soft constraints was also defined:

- *Two Exams in a Row*—For all students, the number of times a student has two exams arranged consecutively should be minimised.
- *Two Exams in a Day*—For all students, the number of times a student has two exams arranged in the same day (excluding adjacent exams) should be minimised.
- *Period Spread*—Its aim is to spread the students' exams over a fixed number of periods.
- *Mixed Durations*—Its aim is to minimise the number of occurrences of exams with different durations that are scheduled in the same room and period.
- *Front Load*—Exams having the largest number of students should be scheduled at the start of the examination session.
- *Room and Period Penalties*—Its goal is to minimise the use of selected rooms or periods in the timetable.

11.3.2.1 Mathematical Formulation

In this section, the main aspects of the ITC 2007 examination timetabling problem mathematical formulation, proposed by McCollum et al. (2012), are given. For more details, please refer to McCollum et al. (2012).

In the problem formulation, the following sets are used:

E: set of exams
P: set of periods
R: set of rooms

Institutional Weights and Parameters

The institutional weights, specified for each dataset (in each input file), are the following:

w^{2R} : weight for "two in a row"
w^{2D} : weight for "two in a day"
w^{PS} : weight for period spread
w^{NMD} : weight for "no mixed duration"
w^{FL} : weight for the front-load penalty

Table 11.3 ITC 2007 benchmark set institutional weights

Dataset	w^{2D}	w^{2R}	w^{PS}	w^{NMD}	w^{FL}
Exam_1	5	7	5	10	100
Exam_2	5	15	1	25	250
Exam_3	10	15	4	20	200
Exam_4	5	9	2	10	50
Exam_5	15	40	5	0	250
Exam_6	5	20	20	25	25
Exam_7	5	25	10	15	250
Exam_8	0	150	15	25	250
Exam_9	10	25	5	25	100
Exam_10	0	50	20	25	100
Exam_11	50	10	4	35	400
Exam_12	10	35	5	5	25

Dataset: ITC 2007 dataset instances; w^{2D}: weight for "two in a day"; w^{2R}: weight for "two in a row"; w^{PS}: weight for period spread; w^{NMD}: weight for "no mixed duration"; w^{FL}: weight for the front-load penalty

The institutional weights are depicted in Table 11.3.

In the input files, two parameters are also specified:

w_r^R : a weight that specifies the penalty for using room r
w_p^P : a weight that specifies the penalty for using period p

Primary Decision Variables

The binary (Boolean) decision variables that fix the assignment are

$$X_{ip}^P = 1 \quad \text{if exam } i \text{ is in period } p, 0 \text{ otherwise} \tag{11.4}$$

$$X_{ir}^R = 1 \quad \text{if exam } i \text{ is in room } r, 0 \text{ otherwise.} \tag{11.5}$$

There are other (secondary) variables that are used to write the constraints and to compute the objective function (McCollum et al., 2012).

Soft Constraints Penalties

The penalties for violations of the various soft constraints are encoded as non-negative secondary variables as follows (McCollum et al., 2012):

C_s^{2R} = "Two in a row" penalty for student s
C_s^{2D} = "Two in a day" penalty for student s
C_s^{PS} = "Period spread" penalty for student s

C^{NMD} = "No mixed duration" penalty
C^{FL} = "Front-load" penalty
C^{P} = "Soft period" penalty
C^{R} = "Soft room" penalty

Objective

The objective function is as follows:

$$Minimise$$
$$\sum_{s \in S} \left(w^{2R} C_s^{2R} + w^{2D} C_s^{2D} + w^{PS} C_s^{PS} \right) + w^{NMD} C^{NMD} + w^{FL} C^{FL} + C^P + C^R. \tag{11.6}$$

There are no separate weights for the room and period penalties, C^R and C^P, as the associated weights were already included in their definitions (McCollum et al., 2012). These are detailed next.

Soft Period Penalty

The soft period penalty, part of the overall penalty, should be calculated on a period-by-period basis. For each period, the penalty is calculated by multiplying the associated penalty (represented by weight w_p^P introduced earlier) by the number of exams timetabled within that period. The soft period penalties C^P are enforced by

$$C^P = \sum_{p \in P} \sum_{i \in E} w_p^P X_{ip}^P. \tag{11.7}$$

Soft Room Penalty

This part of the overall penalty should also be calculated on a period-by-period basis. For each period, if a room used within the solution has an associated penalty, then the penalty for that room for that period is calculated by multiplying the associated penalty (represented by weight w_r^R introduced earlier) by the number of exams using that room. The soft room penalties C^R are enforced by

$$C^R = \sum_{r \in R} \sum_{i \in E} w_r^R X_{ir}^R. \tag{11.8}$$

For details about the full mathematical formulation, please consult (McCollum et al., 2012).

11.4 Proposed Approach

This section describes the two proposed approaches based on the TA metaheuristic, namely the standard TA approach, and an accelerated variant of TA, named FastTA. This section is organised as follows. Section 11.4.1 describes the TA-based search method and the neighbourhood structure used. Section 11.4.2 describes the FastTA approach. Sections 11.4.3 and 11.4.4 describe the application of TA and FastTA to the Toronto and ITC 2007 benchmark sets, respectively.

11.4.1 Threshold Acceptance Metaheuristic

The *threshold acceptance* (TA) (Dueck & Scheuer, 1990) metaheuristic belongs to the family of *simulated annealing* (SA)-based metaheuristics and is structurally similar to SA. The difference relies in that the TA uses a deterministic acceptance criterion, whereas the SA uses a probabilistic one. The TA components are:

- X, solution set
- f, objective function to be minimised over X
- $N(s)$, neighbourhood of each solution s in X
- L, state-space graph induced by X and by the definition of $N(s)$

The TA metaheuristic starts from an initial solution, or state, and proceeds to improve it by moving in the state space of L. In each movement, a neighbouring solution s' of the current solution s is created. The algorithm accepts the neighbour solution s', even if $f(s') > f(s)$, as long as $f(s') - f(s)$ is less than or equal to the current threshold, Q. The threshold starts at a high value and is reduced according to a given cooling schedule. The template of the TA algorithm is shown in Algorithm 11.1.

Many cooling schedules were proposed in the literature (Talbi, 2009). In this chapter, the threshold Q is updated by simulating the exponentially decreasing temperature over time, as used in the metal annealing process. This is achieved by the function $T(t)$:

$$T(t) = Q_{max} \cdot \exp(-R\, t), \tag{11.9}$$

where R is the threshold decreasing rate and Q_{max} is the initial threshold (Q_{max} should have a large value as compared to R). Function $T(t)$ allows for a slow decreasing cooling schedule to be defined, given that a small value of parameter R is defined.

Algorithm 11.1 Steps of the *threshold acceptance* metaheuristic (Talbi, 2009)

Input: Threshold annealing Q_{max}

$s \leftarrow s_0$ ▷ Creation of the initial solution
$Q \leftarrow Q_{max}$ ▷ Initial threshold value
repeat
  repeat ▷ At a fixed threshold
    Generate a random neighbour $s' \in N(s)$
    $E \leftarrow f(s') - f(s)$
    if $E \leq Q$ **then** $s \leftarrow s'$
    end if ▷ Accept the neighbour solution
  until Equilibrium condition ▷ e.g., a given number of iterations executed at each threshold Q
  $Q \leftarrow g(Q)$ ▷ Threshold update
until Stopping criteria satisfied ▷ e.g., $Q \leq Q_{min}$
Output: Best solution found.

In the proposed technique, the *Kempe chain* (Thompson & Dowsland, 1998) neighbourhood is used. Only feasible Kempe chain moves are considered. The Kempe chain heuristic is further explained in detail in Leite et al. (2018).

In the next section, the FastTA search method for solving the ETP is explained.

11.4.2 Accelerated TA Metaheuristic for the ETP

We start by studying, in Sect. 11.4.2.1, the effect of the cooling schedule on the exam move acceptance rate in TA, introducing the basic framework used by the FastTA method. The presented study is similar to the one made for the *fast simulated annealing* metaheuristic in Leite et al. (2019). The FastTA approach is described in Sect. 11.4.2.2.

11.4.2.1 Effect of the Cooling Schedule on the Exam Move Acceptance Rate

In the study carried out in this section, the effect of the cooling schedule on the exam move acceptance rate in TA is analysed. The study undertaken reveals some important properties of the local search operator, which are exploited by the FastTA algorithm. The experiments were performed on the Toronto and ITC 2007 benchmark sets. In the text, the value of the objective function of a given solution is sometimes referred by the terms *cost* and *solution cost*.

As mentioned in Sect. 11.4.1, the cooling schedule in TA is the means by which the threshold is updated. In order to test the TA algorithm under different cooling schedule intensities, two representative cooling schedules were used for the Toronto and ITC 2007 sets: a *light* cooling schedule and an *intensive* one. The cooling

Table 11.4 Threshold acceptance's cooling schedules used in the Toronto and ITC 2007 benchmark sets

Dataset	Type	Q_{Max}	r	k	Q_{Min}	# Evaluations
Toronto	Light	0.1	1×10^{-5}	5	2×10^{-5}	4, 258, 600
	Intensive	0.1	1×10^{-6}	5	2×10^{-5}	42, 585, 970
ITC 2007	Light	1000	1×10^{-5}	5	1×10^{-5}	9, 210, 346
	Intensive	1000	4.5×10^{-6}	5	1×10^{-5}	20, 467, 426

Threshold acceptance's cooling schedule parameters: Q_{max}—initial threshold value, r—cooling rate, k—number of iterations at a fixed threshold, and Q_{min}—final threshold value

schedules' parameters are the following: Q_{max}—initial threshold value, r—cooling rate, k—number of iterations at a fixed threshold, and Q_{min}—final threshold value. The cooling schedule parameters, for the Toronto and ITC 2007 benchmark sets, are depicted in Table 11.4.

In the light cooling schedule, the threshold is updated in a faster way leading to a superficial exploitation of the search space. On the other way, in the intensive cooling schedule, a slower cooling rate is used, leading to a more intensive exploitation of the search space compared to the light cooling schedule.

The parameter selection was set as follows. We have selected an initial threshold value that allows for the great majority of exams to be moved several times, in order to better explore the search space. Graphically, we know that this effect is achieved by having the first threshold bin practically filled in Figs. 11.1 and 11.2 (described below). After several experiments, we have determined that the values for the Q_{max} parameter shown in Table 11.4 were appropriate values. The other cooling schedule parameters, r, k, and Q_{min}, were set as follows. Parameter r (rate) admits two values, in order to have two cooling schedules, a *light* one and an *intensive* one. Parameter k (number of iterations per temperature/threshold) was set to a low value, since the intensification is mainly controlled by the rate parameter. Finally, parameter Q_{min} (minimum temperature/threshold) was set to have an appropriate low threshold, in order for the TA algorithm to accept non-improving states with low probability.

Figures 11.1 and 11.2 illustrate the evolution of the number of accepted exam movements as the TA threshold varies, for Toronto's car92 (see Table 11.1) and ITC 2007's Exam_4 (see Table 11.2) instances, respectively.

The y-axis in the figures represents the exam index. The exams were ordered according to the *largest degree* heuristic (Cheong et al., 2009), i.e., sorted decreasingly by the number of conflicts they have with other exams. Hence, the lower indices represent "difficult" exams, in terms of scheduling complexity, and the higher indices represent "easy" exams.

The x-axis is divided into ten *thresholds bins*. A *threshold bin* is comprised of adjacent TA's thresholds. Each bin is represented by two limiting vertical grid lines, interpreted from the x-axis. Each bin was generated in order to represent an equal number of evaluations, i.e., the TA metaheuristic computes 1/10 of the total number

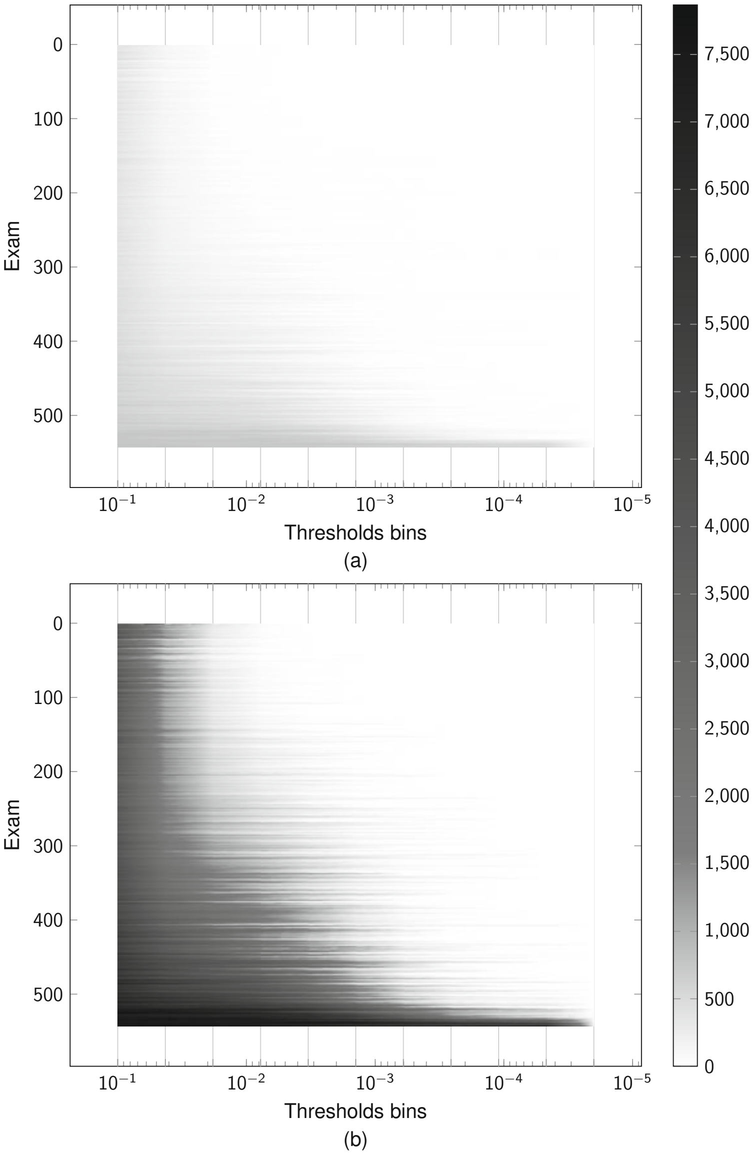

Fig. 11.1 Evolution of the number of accepted exam moves when applying (**a**) *light* and (**b**) *intensive* cooling schedule in the TA algorithm for Toronto's car92 instance

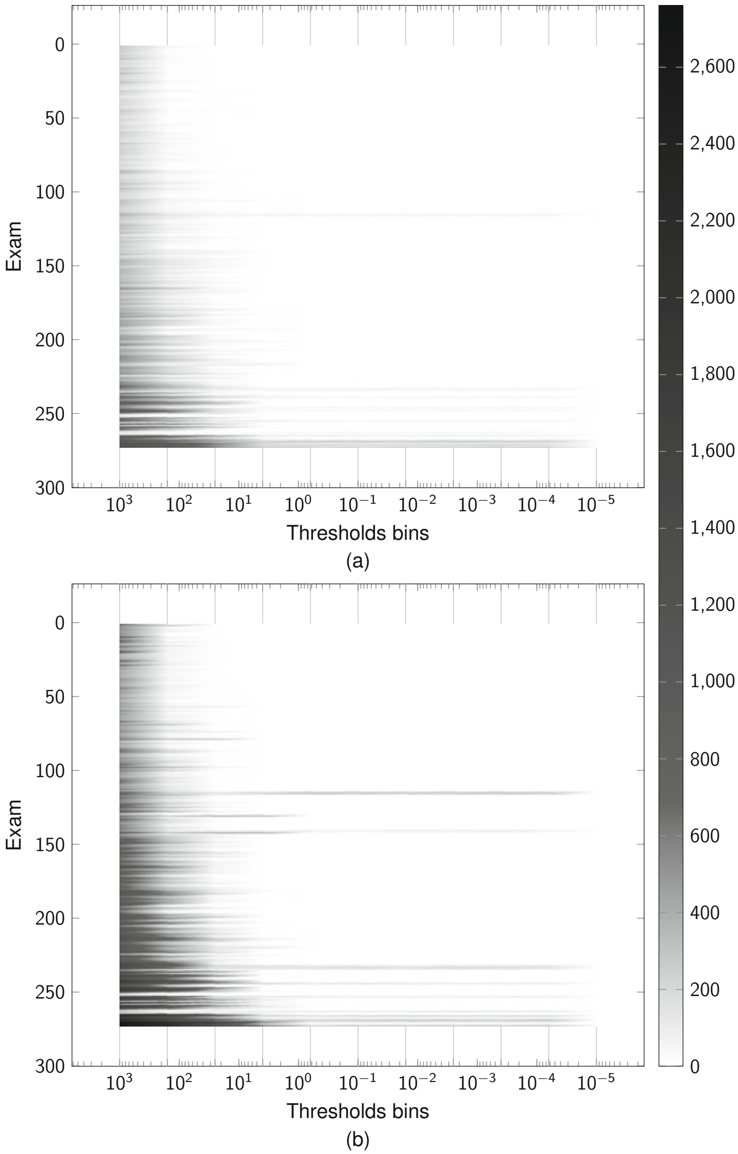

Fig. 11.2 Evolution of the number of accepted exam moves when applying (**a**) *light* and (**b**) *intensive* cooling schedule in the TA algorithm for ITC 2007's Exam_4 instance

of evaluations in each of the ten bins. The gray levels represented in the graph, for each bin on the x-axis and for each exam index on the y-axis, denote the number of accepted states for that exam. Larger values of accepted exam movements are illustrated with darker gray levels.

For the Toronto benchmark set experiment, Fig. 11.1a illustrates the optimisation using a *light* cooling schedule, which yields a cost of 3.87. In Fig. 11.1b, the *intensive* cooling schedule is employed yielding a lower cost of 3.77. The same behaviour is observed for the ITC 2007 benchmark set experiment. In Fig. 11.2a, a *light* cooling schedule is used yielding a cost of 12,898. Using a more *intensive* cooling schedule (Fig. 11.2b), the algorithm yields a lower cost of 12,356.

For each bin, the total number of exams' accepted states/moves is typically lower than the number of evaluations carried out in that bin, as only a fraction of candidate states is accepted by the TA acceptance criterion.

From the figures, one can observe that the more complex exams (having lower indices) only have accepted states/moves in the beginning of the optimisation process, when higher threshold values are set. When lower threshold values are set (e.g., below threshold 1×10^{-2} in the Toronto case), the complex exams start to stick to their final positions, whereas easier exams (with higher indices in the y-axis) continue to have accepted states/moves, being fixed to their final positions only when the threshold value is near the minimum.

As observed from the difference in the top and bottom graphs from Figs. 11.1 and 11.2 (and associated solutions cost), it is crucial to schedule in an optimal or near-optimal way the difficult exams (largest degree ones), in order for the easy exams to be scheduled in an optimal or near-optimal way as well. In this way, a slow cooling schedule is needed for the TA to find the optimal time slots, for the difficult exams, in a first moment, and later for the easy exams.

11.4.2.2 FastTA Algorithm for the ETP

As illustrated in Figs. 11.1 and 11.2, the difficult exams tend to become crystallised when lower threshold values are set in the algorithm. We can see that an exam becomes crystallised when the number of movements in the preceding threshold bin is zero or near zero. If one decided in the algorithm to not expand states of (and therefore, not evaluate) crystallised exams, this would yield a faster algorithm. However, not perturbing a crystallised exam could lead to worse results, if that exam has bins with zero values followed with bins with non-zero values. In this chapter, this faster algorithm variant was implemented, which stops perturbing (and evaluating) an exam when a bin with a zero value is found for that exam. The pseudocode of this faster TA variant, named FastTA, is specified in Algorithm 11.2.

Algorithm 11.2 Template of the *fast threshold acceptance* algorithm

Input: Cooling schedule and starting threshold Q_{max}

1: $prevBin \leftarrow$ nil; ▷ Array containing # accepted moves in the previous bin, initially nil
2: $currBin \leftarrow$ createArray(numExams); ▷ Array containing # accepted moves in the current bin, initialised with zeros
3: $s \leftarrow s_0$; ▷ Generation of the initial solution
4: $Q \leftarrow Q_{max}$; ▷ Starting threshold
5: **repeat**
6:     **repeat** ▷ At a fixed threshold
7:         Generate a random neighbour $s' \in N(s)$;
8: $examToMove \leftarrow$ selectExamFromSolution(s')
9:   **if** $prevBin =$ nil or ($prevBin <>$ nil and $prevBin[examToMove] > 0$) **then** ▷ Evaluate neighbour solution
10:             $E \leftarrow f(s') - f(s)$
11:             **if** $E \leq Q$ **then** $s \leftarrow s'$
12:             **end if** ▷ Accept the neighbour solution
13:   **if** s' was accepted **then**
14: $currBin[examToMove] \leftarrow currBin[examToMove] + 1$
15:   **end if**
16:   **end if**
17:     **until** Equilibrium condition ▷ e.g., a given number of iterations executed at each threshold Q
18:     $Q \leftarrow g(Q)$ ▷ Threshold update
19: $prevBin \leftarrow$ updateBin($Q, currBin$) ▷ If Q is in the next bin, make $prevBin \leftarrow currBin$ and zero $currBin$
20: **until** Stopping criteria satisfied ▷ e.g., $Q \leq Q_{min}$
21: **Output:** Best solution found.

In Algorithm 11.2, lines appearing with numbers in bold face are extensions to the standard TA algorithm, specified in Algorithm 11.1. In the FastTA, all exam perturbations (number of accepted state transitions/moves) are recorded for each bin and exam. Perturbing an exam consists in selecting an exam randomly and checking if the exam's previous bin value is zero. If the value is zero, the exam is crystallised and is not perturbed. Otherwise, the exam is perturbed and the new state move, if accepted by FastTA, is counted in the exam's current threshold bin. As presented in Sect. 11.5, the cost degradation produced by FastTA, compared with TA, is not expressive.

The next two sections describe the application of FastTA to the Toronto benchmark set (uncapacitated problem) and to the ITC 2007 benchmark set (capacitated problem).

11.4.3 Application to the Toronto Benchmark Set

This section describes the application of FastTA to the Toronto benchmark set.

11.4.3.1 Solution Representation and Fitness Function

The adopted solution representation for the Toronto benchmark set is illustrated in Fig. 11.3.

Each solution is represented by an array of time slots, where each time slot contains an array of the scheduled exams in that time slot. For example, in Fig. 11.3 the exams scheduled in time slot t_1 are e_1, e_9, and e_{23}, whereas the exams scheduled in time slot t_2 are e_2, e_8, e_{14}, e_{16}, and e_{17}. The exams allocated to a given period must satisfy the specified hard constraint.

The cost function used is given by Eq. (11.1).

11.4.3.2 Construction of Initial Feasible Timetables

While not explicitly stated in the original paper by Carter et al. (1996), it was discovered experimentally by many researchers that the Toronto set's instances have at least one feasible solution.

The initial solution generation for the Toronto problem uses the *saturation degree* (SD) graph colouring heuristic (Brélaz, 1979). The exams to be scheduled are maintained in a priority queue, which is sorted in non-decreasing order of the number of available periods. In the beginning, all exams have the same priority. The heuristic successively selects a candidate exam randomly and assigns it to a random time slot, until the queue is empty or the top priority exam could not be scheduled in the chosen time slot. In the latter case, the process stops and is restarted generating a new random priority queue with all exams. The process is successful if all exams could be scheduled in a given cycle.

According to conducted tests, the algorithm is able to find a feasible solution within less than five cycles (on average). As a consequence, no further investigation into a more complex construction procedure, which could construct viable solutions, was performed.

11.4.3.3 Neighbourhood Operator

In solving the Toronto timetabling problem instances, the Kempe chain neighbourhood (Thompson & Dowsland, 1998; Demeester et al., 2012) was used. Using the

Fig. 11.3 Solution representation for the Toronto benchmark set (uncapacitated problem)

t_1	t_2	$\cdots$	t_T
e_1	e_2		e_6
e_9	e_8		e_{13}
e_{23}	e_{14}	$\cdots$	e_{15}
	e_{16}		e_{20}
	e_{17}		

Kempe chain neighbourhood, the move operator always produces feasible solutions for the Toronto dataset.

11.4.4 Application to the ITC 2007 Benchmark Set

11.4.4.1 Solution Representation and Fitness Function

Since the ITC benchmark set is capacitated, rooms also have to be considered in the solution. The generic representation of a solution in this case is given in Fig. 11.4. For example, exam e_4 is scheduled in time slot t_1 and room r_1, and exams e_1 and e_6 are scheduled in time slot t_2 and room r_2.

The cost function used is given by Eq. (11.6).

11.4.4.2 Construction of Initial Feasible Timetables

In the ITC 2007 problem, the SD heuristic is also used to generate the initial solution. For complexity reasons, each exam's number of available time slots is calculated taking into account only the *No Conflicts* hard constraint (McCollum et al., 2012) (see Sect. 11.3.2), as an alternative to include all of the hard constraints. The remaining hard constraints are verified when the exam is allocated.

When the SD heuristic starts, instead of generating a priority queue with exams placed in a random fashion, the exams are initially sorted in the priority queue according to their number of *After* hard constraints. In this way, the more constrained exams are scheduled first (Leite et al., 2018).

The SD construction algorithm executes two steps:

Step 1 An exam is extracted from the priority queue, and a random period and room, chosen from the list of available ones, are selected. If all hard requirements are satisfied, the exam is scheduled in that time slot and room, and the exams' priorities (number of available time slots) in the queue are updated, considering only the *No Conflicts* hard constraint. Continue in this fashion until all exams

Fig. 11.4 Solution representation for the ITC 2007 benchmark set (capacitated problem)

	t_1	t_2	⋯	t_T
r_1	e_4	e_9		e_{12}, e_{22}
r_2		e_1, e_6		e_{18}, e_{10}
.	.	.		.
.	.	.	⋯	.
.	.	.		.
r_{R-1}	.	.		.
r_R		e_{20}		e_2

are scheduled or an exam fails to be scheduled due to the absence of free periods/rooms or hard constraints violations. In the latter case, go to Step 2.

Step 2 If there are no free periods or rooms for the selected exam, random values are chosen for these. When the algorithm reaches Step 2, we know that the exam cannot be scheduled in a feasible way due to conflicts with other exams placed in the timetable. To solve this, the conflicting exams are removed from the timetable and the candidate exam is scheduled. The removed conflicting exams are reinserted in the priority queue, and priorities are recomputed as in Step 1. The algorithm then goes to Step 1 again.

In order to avoid cycles, due to repetitive assignments of variables (exams) to the same values (period and room), the *conflict-based statistics* (CBS) (Müller, 2009) structure is employed. For more details, refer to Leite et al. (2018).

11.4.4.3 Neighbourhood Operators

The neighbourhood operators used in this chapter are the same as in Leite et al. (2018). These are:

Room move A randomly chosen exam is scheduled in another room (randomly chosen) in the same time slot.

Slot-Room move A randomly chosen exam is scheduled in other, randomly selected, room and time slot.

These operators may produce infeasible solutions (Leite et al., 2018). In this case, the move is ignored by the FastTA algorithm.

11.5 Experiments

In this section, the experimental evaluation of the FastTA, on the Toronto and ITC 2007 sets, is reported. In Sect. 11.5.1, the TA variants tested in the simulations are described.

Section 11.5.2 describes the algorithm parameter settings specified for the used benchmark sets.

Section 11.5.3 reports the comparison results between FastTA and TA on the Toronto and ITC 2007 benchmark sets.

Sections 11.5.4 and 11.5.5 provide a comparison of FastTA with the state-of-the-art approaches for the Toronto and ITC 2007 benchmark sets, respectively.

The developed algorithms were programmed in the C++ language using the ParadisEO framework (Talbi, 2009). The hardware and software specifications are: Intel Core i7-2630QM, CPU @ 2.00 GHz $\times$ 8, with 8 GB RAM; OS: Ubuntu 18.04 LTS, 64 bit; Compiler used: GCC v. 7.3.0.

For the Toronto benchmark set, the algorithm computation time was nearly 15 hours, at most, given the chosen parameters (Sect. 11.5.2). For the ITC 2007 benchmark set, the computation time was set to 276 seconds, as measured by the provided benchmarking tool from the ITC 2007 site (International Timetabling Competition, 2007).

All obtained solutions were validated using Qu et al.'s validator tool (Qu et al., 2009) (for the Toronto benchmark set) and the ITC 2007s online validator tool (for the ITC 2007 benchmark set).

All statistical tests were carried out with a 95% confidence level. For each tested configuration, ten runs of the algorithm were performed. The statistical significance was assessed using the Friedman test (García & Herrera, 2008). The Java tool in García and Herrera (2008) was used to produce the results of all statistical tests.

For each examination timetabling benchmark set, the source code, the resulting solution files for each instance/run, and the produced statistics, are publicly available in the following Git repositories:

Toronto: https://github.com/nunocsleite/FastTA-ETP-Toronto
ITC 2007: https://github.com/nunocsleite/FastTA-ETP-ITC2007

11.5.1 Compared TA Variants

In the conducted experiments, three TA algorithm variants, named *TA*, *FastTA100*, and *FastTA80*, were tested. These are described as follows:

1. TA—This is the original TA metaheuristic, as described in Algorithm 11.1.
2. FastTA100—This comprises the basic FastTA algorithm, as described in Algorithm 11.2. In the FastTA100 variant, exam perturbations for the current threshold are recorded in the respective threshold bin, i.e., if a selected exam is perturbed, and the new state is accepted, the number of accepted moves for that exam is incremented in the corresponding bin. An exam is only allowed to move if that exam is not crystallised, i.e., the number of accepted moves in the previous threshold bin is non-zero. If the exam is already crystallised, no perturbation is made to that exam until the end of the optimisation process. This leads to a reduction in the number of evaluations taken.
3. FastTA80—This variant is similar to the FastTA100, differing in the way how exams are fixed. An exam becomes crystallised if two conditions are met: the number of accepted moves in the previous threshold bin is zero *and the exam is in the set comprising 80% of the exams with highest degree*, that is, it is considered a "difficult" or largest degree exam (Leite et al., 2019). Perturbations made to large-degree exams are often not accepted when reaching low thresholds, as these perturbations imply a high variation in the cost. On the other side, small-degree exam perturbations yield small fluctuations in the objective function value. The idea of this FastTA variant is to fix large-degree exams as they stop accepting perturbations, and allow the smallest degree exams to move freely, despite having some threshold bins with zero counts.

These TA variants are compared with each other in Sect. 11.5.3 on the reference benchmark sets of Toronto and ITC 2007.

11.5.2 Parameter Settings

This section describes the algorithm parameter settings specified for the Toronto and ITC 2007 benchmark sets.

For the experiments involving the Toronto benchmark set, the cooling schedules used for the TA and FastTA are specified in Table 11.5. Two different cooling schedules were used: a *light* cooling schedule and an *intensive* one. The light cooling schedule was used in the experiments presented in Sect. 11.5.3, whereas the intensive cooling schedule was used to generate the final timetables for the Toronto dataset used in the comparison with the state-of-the-art approaches (Sect. 11.5.4).

Two parameter configurations were used in the conducted experiments for the ITC 2007. In the first configuration, the parameters were manually tuned for each ITC 2007 instance. This configuration was only used in the FastTA variants' comparison (Sect. 11.5.3). In the second configuration, a fixed set of parameters was used for all instances, excepting the cooling rate, which was computed automatically by the optimisation algorithm. The algorithm used to compute the cooling rate in an automatic fashion is described in Algorithm 3 of Leite et al. (2019). The second parameter configuration was used to compare the FastTA100 with the state-of-the-art approaches.

Table 11.6 summarises the cooling schedule parameters used in the first configuration (parameters manually tuned) for the ITC 2007 benchmark set. The parameter values were chosen using as reference the FastTA100 algorithm. Specifically, the cooling schedule values were adapted empirically for each dataset instance while guaranteeing that the FastTA100 computation time was within the ITC 2007 time limit constraint.

For the second parameter configuration, the following parameter set was used: $Q_{Max} = 350$ (initial threshold), $Q_{Min} = 1 \times 10^{-6}$ (final threshold), $k = 5$ (number of iterations at a fixed threshold), and r computed automatically using the algorithm described in Leite et al. (2019).

The neighbourhood operators, the *Room* and *Slot-Room* moves, were selected with equal probability. This value was found after conducting some tuning experiments.

Table 11.5 Threshold acceptance's cooling schedules used in the Toronto benchmark set

Type	Q_{Max}	r	k	Q_{Min}	# Evaluations
Light	0.1	0.001	5	2×10^{-5}	42, 590
Intensive	0.1	5×10^{-7}	5	2×10^{-5}	85, 171, 935

Threshold acceptance's cooling schedule parameters: Q_{max}—initial threshold value, r—cooling rate, k—number of iterations at a fixed threshold, and Q_{min}—final threshold value

Table 11.6 Threshold acceptance's cooling schedules used to solve the different ITC 2007 instances

Dataset	Q_{Max}	r	k	Q_{Min}	# Evaluations
Exam_1	100	4.00×10^{-6}	5	1.00×10^{-6}	23, 025, 856
Exam_2	100	7.00×10^{-6}	5	1.00×10^{-6}	13, 157, 631
Exam_3	100	9.00×10^{-6}	5	1.00×10^{-6}	10, 233, 716
Exam_4	350	4.50×10^{-6}	6	1.00×10^{-6}	26, 231, 263
Exam_5	300	1.10×10^{-5}	5	1.00×10^{-6}	8, 872, 411
Exam_6	300	6.00×10^{-6}	5	1.00×10^{-6}	16, 266, 081
Exam_7	300	8.00×10^{-6}	5	2.00×10^{-6}	11, 766, 346
Exam_8	300	3.00×10^{-6}	5	3.00×10^{-4}	23, 025, 856
Exam_9	300	1.50×10^{-6}	5	3.00×10^{-4}	46, 051, 706
Exam_10	300	1.60×10^{-6}	5	3.00×10^{-4}	43, 173, 476
Exam_11	300	1.20×10^{-5}	5	3.00×10^{-4}	5, 756, 466
Exam_12	300	1.80×10^{-6}	5	3.00×10^{-4}	38, 376, 421
Sum of # evaluations					265, 937, 229

Threshold acceptance's cooling schedule parameters: Q_{max}—initial threshold value, r—cooling rate, k—number of iterations at a fixed threshold, and Q_{min}—final threshold value

11.5.3 *Comparison of FastTA and TA on the Toronto and ITC 2007 Sets*

In this section, we provide a comparison between two FastTA algorithms, FastTA100 and FastTA80, and the standard TA on the Toronto and ITC 2007 benchmark sets. In these experiments, the light cooling schedule was used for the Toronto benchmark set (Table 11.5) and the cooling schedules of Table 11.6 for the ITC 2007 set. An analysis and discussion of results are given at the end of this section.

Tables 11.7 and 11.8 show the solution costs and the corresponding execution times, respectively, for the FastTA100, FastTA80, and TA algorithms, for the Toronto benchmark set. For each algorithm, the minimum and average values, and the standard deviation of ten runs are shown. Tables 11.9 and 11.10 present the same information but for the ITC 2007 benchmark set.

11.5.3.1 Discussion

Analysing the results in terms of solution cost (Tables 11.7 and 11.9), it can be observed that, for the Toronto set (Table 11.7), the results of FastTA variants are in general close to the ones attained by TA, but inferior to TA. However, the FastTA variants use a significantly lower number of evaluations (column "ENP") compared to TA. For the ITC 2007 (Table 11.9), the FastTA100 has results that compete with the TA, obtaining the best average solution cost in four of twelve instances, while

Table 11.7 Solution costs of FastTA100, FastTA80, and TA on the Toronto benchmark set

	FastTA100				FastTA80				TA		
Dataset	ENP	f_{min}	f_{avg}	σ	ENP	f_{min}	f_{avg}	σ	f_{min}	f_{avg}	σ
car92	**57**	5.01	5.06	0.05	52	4.92	4.99	0.05	**4.57**	**4.65**	0.07
car91	**60**	6.22	6.33	0.05	55	6.10	6.24	0.09	**5.65**	**5.84**	0.13
ear83	**74**	36.94	39.21	1.28	66	37.18	38.95	1.65	**35.25**	**37.61**	1.00
hec92	**73**	10.55	10.97	0.25	62	10.36	11.01	0.29	**10.27**	**10.91**	0.27
kfu93	**50**	14.61	15.24	0.43	47	14.47	15.18	0.44	**13.79**	**14.40**	0.37
lse91	**54**	11.61	12.00	0.34	50	11.47	11.95	0.26	**10.63**	**11.45**	0.38
pur93	**71**	8.01	8.10	0.08	60	7.83	7.96	0.10	**6.38**	**6.46**	0.06
rye92	**60**	9.93	10.17	0.17	53	9.86	10.04	0.16	**8.95**	**9.25**	0.21
sta83	**24**	157.06	157.16	0.11	23	157.05	**157.14**	0.11	**157.03**	157.16	0.11
tre92	**60**	8.94	9.19	0.17	55	8.99	9.22	0.18	**8.70**	**8.89**	0.16
uta92	**53**	4.12	4.20	0.05	49	4.04	4.15	0.06	**3.69**	**3.78**	0.07
ute92	**58**	25.15	25.73	0.51	51	25.28	25.66	0.32	**25.01**	**25.41**	0.45
yor83	**81**	39.68	40.72	0.83	67	38.65	39.95	0.93	**37.46**	**39.08**	0.78
Avg.	**60**				53						

The column "ENP" presents the percentage of *evaluations not performed*, on average, by the FastTA variants in comparison with the standard TA. A higher value of ENP means a faster algorithm. f_{min} and f_{avg} represent the minimum and average values of solution cost, respectively. Solution costs are calculated by function f_c, defined in Eq. (11.1). The best results are shown in bold

Table 11.8 Execution times (in seconds) of FastTA100, FastTA80, and TA on the Toronto benchmark set

	FastTA100			FastTA80			TA		
Dataset	t_{min}	t_{avg}	σ	t_{min}	t_{avg}	σ	t_{min}	t_{avg}	σ
car92	**1**	**1.80**	0.42	2	2.10	0.32	6	6.80	0.42
car91	**2**	**2.50**	0.53	**2**	2.70	0.48	9	9.00	0.00
ear83	**0**	**0.30**	0.48	**0**	0.50	0.53	1	1.60	0.52
hec92	**0**	**0.20**	0.42	**0**	0.30	0.48	**0**	0.60	0.52
kfu93	**0**	0.60	0.52	**0**	**0.50**	0.53	2	2.00	0.00
lse91	**0**	**0.80**	0.42	**0**	**0.80**	0.42	1	1.90	0.32
pur93	**6**	**6.50**	0.53	7	7.00	0.00	32	32.50	0.71
rye92	**1**	**1.00**	0.00	**1**	**1.00**	0.00	3	3.60	0.52
sta83	**0**	**0.30**	0.48	**0**	0.40	0.52	**0**	0.50	0.53
tre92	**0**	**0.70**	0.48	**0**	**0.70**	0.48	2	2.20	0.42
uta92	**2**	**2.50**	0.53	**2**	2.60	0.52	7	8.10	0.57
ute92	**0**	**0.50**	0.53	**0**	**0.50**	0.53	1	1.10	0.32
yor83	**0**	0.40	0.52	**0**	**0.30**	0.48	2	2.00	0.00

The best results are shown in bold

Table 11.9 Solution costs of FastTA100, FastTA80, and TA on the ITC 2007 benchmark set

	FastTA100				FastTA80				TA		
Dataset	ENP	f_{min}	f_{avg}	σ	ENP	f_{min}	f_{avg}	σ	f_{min}	f_{avg}	σ
Exam_1	**48**	**4740**	4922.3	96.3	43	4758	4930.2	101.2	4751	**4845.0**	103.9
Exam_2	**1**	395	407.5	7.5	**1**	**390**	404.5	7.6	395	**402.5**	6.3
Exam_3	**8**	9701	10,145.0	231.9	**8**	9514	**9906.1**	265.2	**9465**	9960.9	240.7
Exam_4	**68**	11, 938	**12,432.7**	385.8	60	12, 165	12,841.7	394.5	**11, 802**	12,557.9	627.7
Exam_5	**7**	3100	3498.9	183.1	6	3081	3393.5	177.1	**2953**	**3332.4**	183.7
Exam_6	**17**	25, 985	26,129.0	120.0	16	25, 940	26,149.5	146.0	**25, 790**	**26,037.0**	208.2
Exam_7	**6**	4269	4512.4	132.0	**6**	4269	4462.3	132.0	**4251**	**4440.6**	133.6
Exam_8	**21**	**7284**	**7487.5**	134.8	**21**	7383	7533.0	147.1	7303	7526.1	141.0
Exam_9	**25**	**944**	**996.7**	44.9	23	961	1021.6	44.5	970	1008.5	27.2
Exam_10	**13**	13, 606	13,768.1	108.1	12	**13, 456**	**13,613.7**	169.1	13, 573	13,685.5	80.4
Exam_11	**14**	**30, 590**	**31,672.6**	781.1	**14**	30, 596	32,757.5	1387.9	30, 994	32,543.3	1252.2
Exam_12	23	5201	5249.2	33.4	**24**	**5118**	5241.9	66.9	5149	**5220.6**	51.7
Avg.	**21**				20						

The column "ENP" presents the percentage of *evaluations not performed*, on average, by the FastTA variants in comparison with the standard TA. A higher value of ENP means a faster algorithm. f_{min} and f_{avg} represent the minimum and average values of solution cost, respectively. Solution costs are calculated by the objective function defined in Eq. (11.6). The best results are shown in bold

Table 11.10 Execution times (in seconds) of FastTA100, FastTA80, and TA algorithms on the ITC 2007 benchmark set

Dataset	FastTA100			FastTA80			TA		
	t_{min}	t_{avg}	σ	t_{min}	t_{avg}	σ	t_{min}	t_{avg}	σ
Exam_1	**252**	**267.2**	9.16	259	278.4	8.49	492	502.6	7.06
Exam_2	**260**	**266.2**	4.37	267	273.3	3.74	270	274.5	2.17
Exam_3	**259**	**266.7**	4.47	268	273.3	5.91	289	300.8	8.97
Exam_4	**247**	**256.9**	6.33	286	296.2	7.32	730	746.7	8.77
Exam_5	**226**	**242.4**	16.68	233	247.0	7.47	267	286.3	11.19
Exam_6	207	238.5	20.32	**195**	**219.7**	17.16	261	272.0	5.03
Exam_7	**221**	**243.8**	19.89	247	255.0	4.88	269	272.4	2.27
Exam_8	229	250.2	15.87	**228**	**233.1**	3.51	294	296.5	1.43
Exam_9	230	244.2	11.14	**206**	**229.4**	12.17	297	305.0	4.83
Exam_10	242	249.5	9.44	**229**	**236.4**	4.81	257	263.8	3.85
Exam_11	**219**	**226.2**	6.86	227	232.5	4.7	278	282.3	4.35
Exam_12	210	228.4	11.46	**199**	**214.0**	8.68	275	280.4	3.89

The best results are shown in bold

requiring less evaluations. This difference is explained in part by the light cooling schedule chosen for the Toronto benchmark set in these experiments, which involve a lower number of evaluations in contrast with the cooling schedules used for the ITC 2007 case.

In terms of the performed number of evaluations (column "ENP"), the FastTA100 and FastTA80 execute, respectively, 60% and 53% less evaluations, on average, compared to the TA algorithm, for the Toronto benchmark set. The same indicators for the ITC 2007 give 21% and 20% less evaluations, respectively. Here, we can see a great difference in the number of evaluations not performed for the Toronto set. This fluctuation is explained, as mentioned before, by the use of a light cooling schedule. Moreover, in Sect. 11.5.4, Table 11.11, an intensive cooling schedule is used in the comparison of FastTA100 with the state-of-the-art approaches, and the average number of evaluations not performed is only 38% for the Toronto benchmark set. This shows that the cooling schedule influences the algorithm's behaviour.

In the experiments, the sum of the mean values of the number of evaluations obtained for each instance is 224,160.6 and 259,331.7, respectively, for FastTA100 and FastTA80, in the Toronto case. For the TA, for the Toronto set, the sum of the number of evaluations executed for each instance is 553,670.

For the ITC 2007 case, the sum of the mean values of the number of evaluations is 200,004,835.7 and 204,849,734.1, for FastTA100 and FastTA80, respectively. For the TA, the sum of the number of evaluations executed for each instance is 265,937,229. These values show that the FastTA100 is the technique that performs the lowest number of evaluations on average.

For the FastTA100 applied to Toronto, the number of neighbours not evaluated is equal or greater than 50% on all instances except one, while not degrading the

Table 11.11 Fitness values and computation times (in hours) of FastTA100 algorithm using the *intensive* cooling schedule on the Toronto benchmark set

	Fitness value						Computation time				
Dataset	ENP	f_{min}	f_{med}	f_{max}	f_{avg}	σ	t_{min}	t_{med}	t_{max}	t_{avg}	σ
car92	27	3.71	3.75	3.80	3.75	0.03	2.5	2.6	2.6	2.6	0.03
car91	27	4.38	4.43	4.53	4.44	0.05	2.6	2.7	2.7	2.7	0.02
ear83	62	32.72	32.90	34.13	33.09	0.53	0.4	0.4	0.4	0.4	0.02
hec92	67	10.05	10.20	10.30	10.18	0.08	0.1	0.1	0.1	0.1	0.01
kfu93	31	12.83	12.92	13.07	12.93	0.07	0.5	0.5	0.6	0.5	0.01
lse91	36	9.81	9.96	10.15	9.98	0.13	0.6	0.6	0.6	0.6	0.00
pur93	10	4.11	4.17	4.21	4.17	0.03	10.9	11.0	14.7	11.3	1.20
rye92	32	7.94	8.02	8.08	8.01	0.05	1.2	1.2	1.3	1.2	0.02
sta83	22	157.03	157.06	157.06	157.06	0.01	0.2	0.2	0.2	0.2	0.00
tre92	41	7.63	7.82	7.96	7.78	0.12	0.6	0.6	0.6	0.6	0.01
uta92	21	3.02	3.07	3.11	3.07	0.02	2.3	2.3	2.3	2.3	0.01
ute92	48	24.85	24.85	25.39	24.91	0.17	0.2	0.3	0.3	0.3	0.01
yor83	70	34.68	35.13	35.83	35.23	0.38	0.4	0.4	0.4	0.4	0.01
Avg.	38										

The column "ENP" presents the percentage of *evaluations not performed*, on average, by the FastTA variant in comparison with the standard TA. A higher value of ENP means a faster algorithm. f_{min}, f_{med}, f_{max}, and f_{avg} represent the minimum, median, maximum, and average values of solution cost, respectively. Solution costs are calculated by function f_c, defined in Eq. (11.1)

solution cost value significantly, which is a significant number. On the ITC 2007, the FastTA100 is able to attain between 13 and 68% of neighbours not evaluated on more than half of the datasets.

From Tables 11.8 and 11.10 results, we can conclude that the presented FastTA approaches are globally faster than the TA approach.

Using as criteria the average percentage of the number of evaluations not performed, and also the execution time, the FastTA100 is the best method. However, in terms of solution cost, the TA is better than FastTA.

In the next two sections, the FastTA100 is compared with the state-of-the-art approaches for the Toronto and ITC 2007 benchmark sets, respectively.

11.5.4 Comparison with State-of-the-art Approaches—Toronto Dataset

In this section, we perform a comparison between the FastTA100 approach and other state-of-the-art methodologies, for the Toronto benchmark set. The tested FastTA100 variant uses the *intensive* cooling schedule as specified in Table 11.5.

Table 11.12 Average objective function value obtained by FastTA and by selection of the best algorithms from the literature

Dataset	Ele07	Bur08	Pil10	Dem12	Lei14	Fon15	Alz15	Lei18	FastTA
car92	4.40	3.92	4.28	3.86	3.77	4.27	4.09	**3.72**	3.75
car91	5.20	4.68	5.05	4.64	4.45	4.85	4.52	**4.39**	4.44
ear83	38.30	32.91	36.49	32.69	32.69	34.48	33.66	**32.61**	33.09
hec92	11.40	10.22	11.69	10.06	10.06	10.61	10.90	**10.05**	10.18
kfu93	14.90	13.02	14.42	13.24	13.00	13.76	13.46	**12.83**	12.93
lse91	11.70	10.14	10.95	10.21	9.93	10.39	10.82	**9.81**	9.98
pur93	4.60	4.71	4.70	5.75	**4.17**	—	—	4.18	**4.17**
rye92	10.00	8.06	9.41	8.20	8.06	—	—	**7.93**	8.01
sta83	157.50	157.05	158.07	157.05	**157.03**	157.37	157.16	**157.03**	157.06
tre92	8.70	7.89	8.45	7.79	7.80	8.04	8.09	**7.70**	7.78
uta92	3.50	3.26	3.39	3.17	3.15	3.31	3.23	**3.04**	3.07
ute92	27.00	24.82	27.45	24.88	**24.81**	26.04	25.33	24.83	24.91
yor83	40.40	35.16	39.74	34.83	34.73	36.83	35.69	**34.63**	35.23

The best results are shown in bold. "—" indicates that the corresponding instance was not tested or no feasible solution was obtained. The compared approaches are: Ele07 Eley (2006)—Ant algorithms, Bur08 Burke and Bykov (2008)—Late Acceptance Hill-Climbing, Pil10 Pillay and Banzhaf (2010)—Genetic Algorithm, Dem12 Demeester et al. (2012)—Hyper-heuristic approach, Lei14 Leite et al. (2016)—hybrid evolutionary algorithm, Fon15 Fong et al. (2015)—Hybrid Swarm-Based Approach, Alz15 Alzaqebah and Abdullah (2015)—Hybrid bee colony optimisation, Lei18 Leite et al. (2018)—Hybrid evolutionary algorithm, FastTA—fast threshold acceptance algorithm

Table 11.11 presents the solution cost values and computation times (in hours) for the FastTA100 algorithm with the intensive cooling schedule, tested on the Toronto benchmark set. The minimum, median, maximum, average, and standard deviation values are shown for the solution cost and computation time.

In Tables 11.12, 11.13, 11.14, 11.15, the compared approaches are identified by an acronym of the first author's name and publication's year. The compared authors are: Ele07—Eley (2006), Bur08—Burke and Bykov (2008), Pil10—Pillay and Banzhaf (2010), Dem12—Demeester et al. (2012), Lei14—Leite et al. (2016), Fon15—Fong et al. (2015), Alz15—Alzaqebah and Abdullah (2015), and Lei18—Leite et al. (2018).

In their papers, few of the compared authors published their source code, and few published the solution files of the executed runs, preventing that a study based on distributions could be done. Thus, comparisons are done using the *best* and *average* of solution cost values.

Table 11.12 presents a comparison of the average results obtained by the state-of-the-art approaches and the FastTA.

Table 11.13 Average ranking of Friedman's test for the compared methods, considering the complete Toronto dataset (13 instances). The lower the rank, the better the algorithm's performance

Algorithm	Rank
Lei18	1.35
Lei14	2.50
FastTA	3.12
Dem12	4.04
Bur08	4.31
Pil10	6.15
Ele07	6.54

The column *Rank* denotes the average rank (dimensionless value) computed according to Friedman's test

Table 11.14 Adjusted p-values (Friedman) produced by running Holm's test (Lei18 is the control algorithm)

Lei18 vs.	Unadjusted p	p_{Holm}
Ele07	$8.90.10^{-10}$	$\mathbf{5.34.10^{-9}}$
Pil10	$1.39.10^{-8}$	$\mathbf{6.97.10^{-8}}$
Bur08	0.000,474	**0.001,90**
Dem12	0.001,49	**0.004,46**
FastTA	0.0368	0.0736
Lei14	0.173	0.173

Values marked in boldface represent statistically significant values

Table 11.15 Adjusted p-values (Friedman) of multiple algorithm comparison obtained by Holm's procedure

i	Hypothesis	Unadjusted p	p_{Holm}
1	Ele07 vs. Lei18	$8:90.10^{-10}$	$\mathbf{1.87.10^{-8}}$
2	Pil10 vs. Lei18	$1.39.10^{-8}$	$\mathbf{2.79.10^{-7}}$
3	Ele07 vs. Lei14	$1.88.10^{-6}$	$\mathbf{3.57.10^{-5}}$
4	Pil10 vs. Lei14	$1.62.10^{-5}$	**0.000,291**
5	Ele07 vs. FastTA	$5.35.10^{-5}$	**0.000,909**
6	Pil10 vs. FastTA	0.000,336	**0.005,37**
7	Bur08 vs. Lei18	0.000,474	**0.007,11**
8	Dem12 vs. Lei18	0.001,49	**0.0208**
9	Ele07 vs. Dem12	0.003,17	**0.0412**

Only statistically significant values are shown (marked in boldface)

11.5.4.1 Statistical Analysis

In this section, a statistical analysis of the analysed algorithms for the Toronto benchmark set is presented. The statistical methods and definitions presented in this section were also used in the experiments made in Sect. 11.5.5.1, involving the ITC 2007 benchmark set.

We have performed $1 \times N$ multiple comparisons tests, where a control method is highlighted (the best performing algorithm) through the application of the test, and have also performed $N \times N$ comparisons, considering all existing pairs of algorithms (Derrac et al., 2011). All hypotheses of equality can be tested by the application of a set of post hoc procedures. In the multiple comparison tests (both $1 \times N$ and $N \times N$ comparisons), the Friedman's test is used. For the post hoc tests, the Holm's procedure was used.

The null hypothesis H_0 and the alternative hypothesis H_1 are defined as follows. The null hypothesis is a statement of no effect or no difference (in our case, significant differences between algorithms), whereas the alternative hypothesis represents the presence of an effect or a difference (Derrac et al., 2011).

Once Friedman's test rejects the null hypothesis, we can proceed with a post hoc test in order to find the concrete pairwise comparisons that produce differences.

We now present a statistical analysis of the obtained average results (Table 11.12) for the Toronto benchmark set.

Table 11.13 summarises the ranks obtained by the Friedman test. The p-value computed by the Friedman test is 9.80×10^{-11}, which is below the significance interval of 95% ($\alpha = 0.05$). This confirms that there exists a significant difference in the observed results, and asserts that Lei18 has the best performance.

Table 11.14 presents adjusted p-values of the post hoc Holm's test when Lei18 is the control method. Holm's test asserts that Lei18 improves the results of all algorithms with $\alpha = 0.05$, except for Lei14 and FastTA.

Table 11.15 presents the adjusted p-values for the same studied scenario, obtained using the Holm's procedure, and showing pairwise comparisons. Only cases having significant differences are shown.

11.5.4.2 Discussion

Analysing the results of Table 11.12, we can state that FastTA obtains the best average result on one Toronto instance, reaching results that are near to the results of the best state-of-the-art algorithms.

The statistical test results substantiate our conclusions: FastTA ranks third among seven algorithms (Table 11.13), where Lei18 has the best performance. Post hoc tests assert that Lei18 improves the results of all algorithms, except for Lei14 and FastTA.

Finally, analysing the results of the multiple algorithm comparison ($N \times N$) from Table 11.15, we can confirm the same conclusions of Table 11.14 and also that Lei14 and FastTA are better than Ele07 and Pil10 and that Dem12 is better than Ele07. From these tables, we can say that Lei18 and Lei14 are not better, with statistical significance, than FastTA.

The computation times of the techniques presented in Table 11.12 can be consulted in (see Leite et al., 2018, Appendix B). Analysing the competitors' running times with the FastTA computation times (Table 11.11), we can see that FastTA is much faster than Lei14 and Lei18 requiring only 11.3 h for pur93, and between 2.3 and 2.7 h for the other medium-size instances, namely car92, car91, and uta92, on average. For these instances, Lei14 requires between 24 and 48 h, and Lei18 requires 48 h for all instances, on average.

11.5.5 Comparison with State-of-the-Art Approaches—ITC 2007 Dataset

In this section, we perform a comparison between the FastTA100 approach and other state-of-the-art methodologies, for the ITC 2007 case. The tested FastTA100 variant uses a cooling rate computed automatically as mentioned in Sect. 11.5.2.

Table 11.16 presents the solution cost values and computation times (in seconds) for the FastTA100 algorithm with rate computed automatically, tested on the ITC 2007 benchmark set. The minimum, median, maximum, average, and standard deviation values are shown for the solution cost and computation time.

In Tables 11.17, 11.18, 11.19, 11.20, 11.21, the compared approaches are identified by an acronym of the first author's name and publication's year. The compared authors are: Gog08—Gogos et al. (2008), Ats08—Atsuta et al. (2008) McCollum et al. (2010), Sme08—De Smet (2008) McCollum et al. (2010), Pil08—Pillay (2008) McCollum et al. (2010), Mul09—Müller (2009), Col09—McCollum et al. (2009), Dem12—Demeester et al. (2012), Gog12—Gogos et al. (2012), Byk13—Bykov and Petrovic (2013), Ham13—Hamilton-Bryce et al. (2013), Alz14—Alzaqebah and Abdullah (2014), Alz15—Alzaqebah and Abdullah (2015), Bat17—Battistutta et al. (2017), Lei18—Leite et al. (2018), Lei19—Leite et al. (2019).

In their papers, few of the compared authors published the algorithm source code and solution files of the executed runs, preventing that a study based on distributions

Table 11.16 Fitness values and computation times (in seconds) of FastTA100 (rate computed automatically) on the ITC 2007 benchmark set

Dataset	Fitness value						Computation time				
	ENP	f_{min}	f_{med}	f_{max}	f_{avg}	σ	t_{min}	t_{med}	t_{max}	t_{avg}	σ
Exam_1	44	5089	5333.0	5434	5313.7	98.13	115	128.0	143	129.0	8.22
Exam_2	1	395	410.0	432	409.7	10.58	252	264.0	269	262.4	5.40
Exam_3	8	9711	10,087.5	10,766	10,091.5	311.62	214	227.0	232	225.1	5.65
Exam_4	69	12, 235	12,992.0	13,735	13,011.0	536.97	61	67.0	72	66.3	3.16
Exam_5	7	3184	3455.5	3984	3470.3	212.77	167	172.0	188	173.0	6.00
Exam_6	16	25, 975	26,100.0	26,355	26,135.5	117.72	189	219.0	237	215.5	14.92
Exam_7	6	4369	4542.5	4635	4515.1	100.56	211	225.0	239	224.1	7.82
Exam_8	27	7488	7662.0	7813	7671.2	105.44	139	164.5	174	163.6	9.52
Exam_9	30	985	1023.5	1046	1024.2	20.19	149	159.0	172	160.0	7.60
Exam_10	15	13, 487	13,707.5	13,960	13,703.7	132.66	205	219.0	229	218.5	8.30
Exam_11	15	32, 189	33,795.5	35,745	33,938.1	1243.55	175	185.0	191	184.6	5.38
Exam_12	27	5148	5232.5	5344	5233.0	60.80	150	161.0	180	162.2	8.24
Avg.	22										

The column "ENP" presents the percentage of *evaluations not performed*, on average, by the FastTA variant in comparison with the standard TA. A higher value of ENP means a faster algorithm. f_{min}, f_{med}, f_{max}, and f_{avg} represent the minimum, median, maximum, and average values of solution cost, respectively. Solution costs are calculated by the objective function defined in Eq. (11.6)

Table 11.17 Minimum solution cost obtained by the ITC 2007 finalists' approaches and the FastTA

Dataset	Mul09	Gog08	Ats08	Sme08	Pil08	**FastTA**
Exam_1	**4370**	5905	8006	6670	12, 035	5089
Exam_2	400	1008	3470	623	2886	**395**
Exam_3	10, 049	13,771	17,669	—	15, 917	**9711**
Exam_4	18, 141	18,674	22,559	—	23, 582	**12, 235**
Exam_5	**2988**	4139	4638	3847	6860	3184
Exam_6	26, 585	27,640	29,155	27,815	32, 250	**25, 975**
Exam_7	**4213**	6572	10,473	5420	17, 666	4369
Exam_8	7742	10,521	14,317	—	15, 592	**7488**
Exam_9	1030	1159	1737	1288	2055	**985**
Exam_10	16, 682	—	15,085	14,778	17, 724	**13, 487**
Exam_11	34, 129	43,888	—	—	40, 535	**32, 189**
Exam_12	5535	—	5264	—	6310	**5148**

The best solutions are indicated in bold. "—" indicates that the corresponding dataset is not tested or a feasible solution was not obtained. The compared approaches are: Mul09 Müller (2009)—Hybrid local search, Gog08 Gogos et al. (2008)—GRASP metaheuristic, Ats08—Atsuta et al. (2008) McCollum et al. (2010)—Constraint satisfaction problem solver adopting a hybridisation of local search, Sme08—De Smet (2008) McCollum et al. (2010)—*Tabu search* metaheuristic, Pil08—Pillay (2008) McCollum et al. (2010)—Approach based on cell biology, FastTA—*fast threshold acceptance* algorithm

could be done. Thus, comparisons are done using the *best* and *average* of solution cost values.

Table 11.17 presents a comparison between the ITC 2007s five finalists and the FastTA, considering the solutions' minimum cost. In Table 11.18, the average results obtained by the state-of-the-art approaches and the FastTA are compared.

11.5.5.1 Statistical Analysis

We now present a statistical analysis of the obtained average results (Table 11.18) for the complete ITC 2007 benchmark set (12 instances).

Table 11.19 summarises the rank obtained by the Friedman test (only algorithms that have values for all instances are considered). The p-value computed by the Friedman test, 6.18×10^{-8}, is below the significance interval of 95% ($\alpha = 0.05$), asserting that there exists a significant difference in the compared results. Byk13 has the best performance.

Table 11.20 presents the post hoc Holm's test adjusted p-values, where Byk13 is the control method. Holm's test asserts that Byk13 improves the results of all algorithms except for Bat17 and Lei19, with $\alpha = 0.05$.

Table 11.21 presents the adjusted p-values for the same studied scenario, obtained using the Holm's procedure, and showing pairwise comparisons. Only cases having significant differences are shown.

Table 11.18 Comparison of the average results obtained by the FastTA algorithm with the state-of-the-art approaches on the ITC 2007 benchmark set

Dataset	Col09	Dem12	Gog12	Byk13	Ham13	Alz14	Alz15	Bat17	Lei18	Lei19	**FastTA**
Exam_1	4799	6330.20	5032	4008	5469	5517.30	5227.81	**3926.96**	6478.20	5231.60	5313.70
Exam_2	425	612.50	**404**	**404**	450	537.90	457.55	407.72	572.90	405.10	409.70
Exam_3	9251	23,580.00	9484	**8012**	10, 444	10,324.90	10,421.64	8849.46	13,680.50	9940.10	10,091.50
Exam_4	15, 821	—	19,607	13, 312	20, 241	16,589.10	16,108.27	15,617.82	15,493.70	**12,992.50**	13,011.00
Exam_5	3072	5323.00	3158	**2582**	3185	3631.90	3443.72	2849.00	4155.60	3490.40	3470.30
Exam_6	25, 935	28,578.13	26,310	**25, 448**	26, 150	26,275.00	26,247.27	26,081.35	26,873.00	26,008.50	26,135.50
Exam_7	4187	6250.00	4352	3893	4568	4592.40	4415.00	**3661.64**	5844.40	4534.70	4515.10
Exam_8	7599	9260.90	8098	**6944**	8081	8328.80	8225.81	7729.46	8942.30	7602.60	7671.20
Exam_9	1071	1255.90	—	**949**	1061	—	—	991.57	1080.30	1017.60	1024.20
Exam_10	14, 552	16,113.33	—	**12, 985**	15, 294	—	—	13,999.56	14,208.70	13,631.70	13,703.70
Exam_11	29, 358	—	—	**25, 194**	44, 820	—	—	27,781.50	43,693.56	31,792.20	33,938.10
Exam_12	5699	5829.14	—	**5181**	5464	—	—	5550.20	5249.00	5204.80	5233.00

The best solutions are indicated in bold. "—" indicates that the corresponding dataset was not tested or a feasible solution was not obtained. The compared approaches are: Col09 McCollum et al. (2009)—*Great deluge* metaheuristic, Dem12 Demeester et al. (2012)—Hyper-heuristics, Gog12 Gogos et al. (2012)—GRASP metaheuristic, Byk13 Bykov and Petrovic (2013)—*Hill-climbing* variant, Ham13 Hamilton-Bryce et al. (2013)—*Great deluge* metaheuristic, Alz14 Alzaqebah and Abdullah (2014)—*Bee colony optimisation*, Alz15 Alzaqebah and Abdullah (2015)—*Bee colony optimisation*, Bat17 Battistutta et al. (2017)—*simulated annealing*, Lei18 Leite et al. (2018)—*Cellular memetic algorithm*, Lei19 Leite et al. (2019)—*simulated annealing*, FastTA—*fast threshold acceptance* algorithm

Table 11.19 Average ranking of Friedman's test for the compared methods, considering the complete dataset (12 instances). The lower the rank, the better the algorithm's performance

Algorithm	Rank
Byk13	1.33
Bat17	3.08
Lei19	3.25
Col09	4.08
FastTA	4.08
Ham13	5.92
Lei18	6.25

The column *Rank* denotes the average rank (dimensionless value) computed according to Friedman's test

Table 11.20 Adjusted *p*-values (Friedman) produced by running Holm's test (Byk13 is the control algorithm)

Byk13 vs.	Unadjusted p	p_{Holm}
Lei18	$2.48.10^{-8}$	$\mathbf{1.49.10^{-7}}$
Ham13	$2.03.10^{-7}$	$\mathbf{1.01.10^{-6}}$
FastTA	0.001,82	**0.007,28**
Col09	0.001,82	**0.007,28**
Lei19	0.0298	0.0595
Bat17	0.0472	0.0595

Values marked in boldface represent statistically significant values

Table 11.21 Adjusted *p*-values (Friedman) of multiple algorithm comparison obtained by Holm's procedure

i	Hypothesis	Unadjusted p	p_{Holm}
1	Byk13 vs. Lei18	$2.48.10^{-8}$	$\mathbf{5.20.10^{-7}}$
2	Byk13 vs. Ham13	$2.03.10^{-7}$	$\mathbf{4.05.10^{-6}}$
3	Bat17 vs. Lei18	$3.30.10^{-4}$	**0.006,27**
4	Lei18 vs. Lei19	$6.70.10^{-4}$	**0.0121**
5	Ham13 vs. Bat17	0.001,32	**0.0224**
6	Byk13 vs. FastTA	0.001,82	**0.0291**
7	Col09 vs. Byk13	0.001,82	**0.0291**
8	Ham13 vs. Lei19	0.002,50	**0.0350**

Only statistically significant values are shown (marked in boldface)

11.5.5.2 Discussion

Analysing the results, we observe that the FastTA is able to compete with the ITC 2007 finalists (Table 11.17), being superior on all instances except three. With respect to average results (Table 11.18), the FastTA is also able to compete with the state-of-the-art approaches.

The employed statistical tests on the average results support our observations: the FastTA is ranked in the fifth position among seven algorithms (Table 11.19), where Byk13 is considered the best approach; Table 11.20, containing the adjusted *p*-

values obtained by Holm's test comparing the control algorithm with the remaining algorithms ($1 \times N$ comparison), allows to ascertain that Byk13 is better than all methods except for Bat17 and Lei19. Finally, analysing the results of the multiple algorithm comparison ($N \times N$) from Table 11.21, we can confirm the same conclusions of Table 11.20 and also ascertain that both Bat17 and Lei19 are better than Ham13 and Lei18. From these tables, we can say that only Byk13 is better than FastTA. The obtained results are statistically significant.

11.6 Conclusions

In the present work, a two-phase hybrid metaheuristic for solving the examination timetabling problem is proposed. In the first phase, initial solutions are generated using the saturation degree graph colouring heuristic. In the second phase, a novel variant of the *threshold acceptance* (TA) is employed. The proposed TA, named *FastTA*, is able to effectively reduce the number of evaluations performed without worsening the optimisation results in a significant way.

The standard TA and proposed FastTA were evaluated using the public Toronto and ITC 2007 benchmark sets. The experiments state that FastTA is faster than TA, as FastTA uses 38 and 22% less evaluations, on average, for the Toronto and ITC 2007 sets, respectively. In terms of solution cost, the FastTA is competitive with the TA algorithm on the ITC 2007 attaining the best average value in four out of twelve instances.

Compared with the state-of-the-art approaches, the FastTA is competitive with the analysed algorithms on both Toronto and ITC 2007 benchmark sets. The algorithm comparison carried out confirms that, for the Toronto set, none of the compared algorithms is better than FastTA. For the ITC 2007 set, only one algorithm, Byk13, is better than the FastTA. These results have statistical significance.

The main contribution/value of this chapter is the proposal of a new acceptance criterion for the TA metaheuristic, which leads to a significantly faster variant (FastTA), and its application to solve public examination timetabling benchmark sets.

The future work can be divided into three paths. Firstly, we intend to study how FastTA can be adapted in order to solve educational problems of other ITC 2007 tracks (course timetabling and post-enrolment course timetabling tracks), and also to other optimisation problems. We think that one of the major tasks relies in the problem representation within the FastTA framework, i.e., how a given solution is perturbed and how the new states are accepted and counts are recorded in each threshold bin.

A second research path will involve the design of other neighbourhood movements and its combination with the presented ones. For example, simpler neighbourhood operators, such as the ones used in Müller (2009), could be combined with Kempe chain ones.

One of the important algorithmic components is the TA cooling rate. In this chapter, the cooling rate is set in an adaptive way based on a simulation made at runtime. The third research line will encompass the study of improved methods of adapting the TA's cooling rate based on the actual optimisation time budget.

Appendix

This appendix presents, in Table 11.22, a literature review of recent methodologies applied to solve educational timetabling problems for Higher Education (HE).

Table 11.22 Characteristics of recent methodologies applied to solve educational timetabling problems

Author (year)	Type of HE timetabling problem	Methodology/ algorithm	Where applied	# Hard Constraints	# Soft Constraints
Our proposal—FastTA technique	Exam timetabling	FastTA (threshold acceptance)	Toronto & ITC 2007 (track 1) sets	2 & 8	1 & 6
Leite et al. (2019)	Exam timetabling	FastSA (simulated annealing)	ITC 2007 (track 1)	8	6
June et al. (2019)	Exam timetabling	Constraint programming and simulated annealing	UMSLIC (university)	—	—
Battistutta et al. (2017)	Exam timetabling	Simulated annealing	ITC 2007 (track 1)	8	6
Woumans et al. (2016)	Exam timetabling	Column generation	KU Leuven campus Brussels (Belgium) & Toronto sets	— & 2	— & 1
Bellio et al. (2016)	Curriculum-based course timetabling	Simulated annealing	ITC 2007 (track 3)	4	4
Bykov and Petrovic (2016)	Exam timetabling	Hill-climbing-based	ITC 2007 (track 1)	8	6
Bettinelli et al. (2015)	Curriculum-based course timetabling	Math. models lower bounds, exact and heuristic	ITC 2007 (track 3)	4	4
Li et al. (2015)	Exam timetabling	Search based on evolutionary ruin and stochastic rebuild	Toronto	2	1
Alzaqebah and Abdullah (2015)	Exam timetabling	Bee colony optimisation	Toronto & ITC 2007 (track 1) sets	2 & 8	1 & 6
Cheong et al. (2009)	Exam timetabling	Bi-objective hybrid evolutionary algorithm	Toronto (capacitated)	3	1

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Chapter 12
Robust Efficiency via Average Correlation: The Case of Academic Departments

Zilla Sinuany-Stern and Lea Friedman

Abstract Many types of efficiency methods for decision-making units (DMUs) have been suggested in the literature. Often in the same application, several efficiency methods are given, making it hard for decision makers to choose which efficiency method to use. This chapter provides a simple method to choose a robust efficiency, by calculating the average correlations of each method with all other methods. This robust method is applied to the case of 21 academic departments within a university, taken from the literature, with two inputs and three outputs. A variety of data envelopment analysis (DEA) methods for measuring DMUs' efficiencies are considered here: constant return to scale (CRS), variable return to scale (VRS), super efficiency (SE), and cross-efficiency (CE). A few multivariate statistical efficiency methods in the DEA context are also used: discriminant analysis, canonical correlation, and regression analysis. For this case study, the robust continuous efficiency scale method turned out to be the CE-CRS method. For validating the results, we also used rankings of the efficiencies, and applied nonparametric statistical tests. Since the two inputs used in the case study had monetary values, we also created a one-input model using the sum of the two inputs. Thus, we were able to use, in addition to the above-mentioned efficiency methods, a version of stochastic frontier analysis via multiple linear regression. Even in this case, CE-CRS turned out to be the robust efficiency method, including for the ranks of efficiencies.

Keywords Robust efficiency · Data envelopment analysis · DEA · Higher education · Cross efficiency · Ranking · Multivariate statistics · Stochastic efficient frontier

Z. Sinuany-Stern (✉) · L. Friedman
Department of Industrial Engineering and Management, Ben Gurion University of the Negev, Beer-Sheva, Israel
e-mail: zilla@bgu.ac.il

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12.1 Introduction

Data envelopment analysis (DEA; Charnes et al., 1978) deals with the efficiency of the decision-making units (DMUs) of an organization, with multiple inputs and multiple outputs, when the weights (prices) are measured by various units and unknowns (the weights are not even agreed upon). DEA provides a dichotomy, splitting DMUs into two groups: efficient and inefficient. Over the years, the popularity of DEA has grown tremendously; Emrouznejad and Yang (2018) reported about 10,300 DEA-related journal articles.

In their survey of DEA applications, Liu et al. (2013) found that education is one of the five areas of application where DEA is most used. Similarly, Sinuany-Stern and Sherman (2014), in their volume on operations research in the public sector and nonprofit organizations, point out that the most-used methodology in their volume is DEA. Historically, education is the first area where DEA was applied (Bessent & Bessent, 1980; Charnes et al., 1981).

Intensive literature reviews are devoted to the use of DEA in higher education (HE); for example, Johnes et al. (2017) reviewed the DEA literature in tertiary education (ibid sections 4 and 5); Thanassoulis et al. (2016, section 3) reviewed DEA in HE; De Witte and Lopez-Torres (2017) provided a comprehensive review of DEA in education, including HE. All the above present a large variety of efficiency models, including DEA efficiency models used in the HE context.

Many efficiency methods have been suggested in the literature; some are DEA based, some are multivariate statistic scales, and some combine both. For example, De la Torre et al. (2016) integrated DEA and multidimensional scaling, discussing the potential complementarities and advantages of combining both methodologies, to reveal the efficiency framework and institutional strategies of the Spanish HE system. Bougnol and Dulá (2006) highlight the validity of DEA as a ranking tool, as applied to assess the performance of universities, using DEA rankings and university rankings based on “Top American Research Universities” by the University of Florida. Pino-Mejías and Luque-Calvo (2021) also used DEA multi-criteria decision-making and principal component analysis for rank-scaling universities based on their international rankings—they do not use inputs for DEA, but rather provide an artificial input of a vector of ones. Sinuany-Stern et al. (1994) used DEA and discriminant analysis to analyze the efficiency of academic departments in a specific university in Israel.

Around the practical quest for full rank-scale efficiency, many efficiency rank-scaling methods have been developed (Adler et al., 2002). Often, several types of efficiencies are given in the same application, making it hard for the decision makers to know which one to choose. This chapter provides a simple method to choose a robust efficiency. Once several efficiency methods are considered in a specific application, our method suggests, first, to calculate the correlations between all pairs of efficiency scales, and then, to calculate for each efficiency method the average correlation of each with all other efficiency methods. The efficiency method with the maximal average correlation is to be chosen as the robust method for the specific application. Pearson correlation and/or Spearman rank correlation may be applied, for validating the results.

The robust efficiency method is applied in this chapter to a set of data from Sinuany-Stern et al. (1994), including 21 academic departments within a university, based on two inputs and three outputs (out of the four original outputs). A variety of DEA methods are used: constant return to scale (CRS), variable return to scale (VRS), super efficiency (SE), and cross-efficiency (CE). In addition, we apply a few other multivariate statistical methods to generate efficiency scales in the DEA context: discriminant analysis, and canonical correlation (Adler et al., 2002). Moreover, by adding the two original inputs we end up with one input and three outputs; thus, multiple regression is utilized to generate a form of stochastic frontier analysis, creating an additional efficiency scale from the regression errors.

In Sect. 12.2, robust efficiency is outlined; Sect. 12.3 lays out all the efficiency methods used for the case study given in Sect. 12.4; in Sect. 12.5 the results are presented; Sect. 12.6 repeats the analyses for one input; and Sect. 12.7 concludes the chapter.

12.2 Robust Efficiency

Let us assume that there are T efficiency methods for evaluating n DMUs, in which Et is an n-dimensional vector for efficiency method t, where $t = 1 \ldots T$. The procedure for finding the robust efficiency method from a set of T feasible methods is as follows:

(a) Calculate the efficiency vector Et (n-dimensional) for all the T methods.
(b) Calculate the correlation $C(Et, Es)$ between the Et and Es efficiency vectors for each pair of methods, t and s.
(c) For each efficiency method t, calculate ACt, the average of its correlations with all other methods, $s = 1 \ldots T$ (excluding t):

$$ACt = \sum\nolimits_{s=1\ldots T,\neq t} C\,(Et, Es)\,/\,(T-1)\,.$$

(d) Find $ACt^* = \max\{ACt\}$, for $t = 1 \ldots n$.
(e) The robust methodology is t^*.

To avoid the issue of the scale range of the efficiencies, it is recommended to also use their ranks (e.g., Appendix Table 12.10). Thus, nonparametric correlations can be used too, i.e., Spearman rank correlation, in addition to the Pearson correlation. The ranks may give a better look at the similarity among efficiency methods with various scales; for example, the five efficiency scales in Table 12.2, where some have only positive values, and some have positive and negative values. Moreover, the robustness of the chosen best method via Pearson correlation is strengthened when the Spearman rank correlation points to the same efficiency method.

Another method, for verifying the similarity among the ranking methods, is the Friedman nonparametric ANOVA test for ranks—the significance of the similarity of the ranks can be tested (Friedman & Sinuany-Stern, 1998).

Not all efficiency methods provide a full-scale ranking; some only divide the DMUs into two groups, efficient and inefficient. Thus, to be able to apply the robust efficiency outlined above, a screening process is needed to select the final feasible efficiency methods to be considered for a specific application.

12.3 Efficiency Methods Used for the Case Study

We refer here to nine efficiency methods, which are shown in Table 12.1. Included here are five of the major DEA versions (E1–E5) and four stochastic multivariate statistical methods, which are combined within the DEA context. The main features of each method are given later in this section, to understand the advantages of each efficiency method and its limitations, thus highlighting the need to consider several methods.

Table 12.1 List of efficiency methods considered for the case of academic departments

Et	Method considered[a]	Method chosen for this case study	Main features[b]	Scale range	Common weights for all DMUs?
E1	CRS	Indirectly for E5, E6	Dich. & Det.	(0,1]	No
E2	SE-CRS	Yes	Scale & Det.	$(0,\infty)$	No
E3	VRS	Indirectly for E7	Dich. & Det.	(0,1]	No
E4	SE-VRS	No due to infeasibility	Scale & Det.	$(0,\infty)$	No
E5	CE-CRS	Yes	Scale & Det.	(0,1)	Yes
E6	Disc-CRS	Yes	Scale & Stoc.	$(-4,4)$	Yes[c]
E7	Disc-VRS	Yes	Scale & Stoc.	$(-4,4)$	Yes[c]
E8	CCA	Yes	Scale & Stoc.	$(0,\infty)$	Yes[c]
E9	Regression	Only when 1 input	Scale & Stoc.	(∞,∞)	Yes[c]

[a]CRS—constant return to scale; VRS—variable return to scale; SE—super efficiency; CE—cross efficiency; Disc—discriminant analysis; CCA—canonical correlation

[b]Dich.—provides dichotomy division: efficient and inefficient; Det.—deterministic; Scale—provides full scale; Stoc.—stochastic model

[c]For E6 and E7 the input weights must be negative, and the output weights must be positive; for E8 inputs and outputs must all have the same sign; for E9 all coefficients must be positive

12.3.1 CRS Method

CRS DEA efficiency (Charnes et al., 1978) is the original DEA efficiency method. The CRS efficiency method finds, for each DMU, the ideal weights for the inputs and outputs which maximize the ratio between its sum of weighted outputs and the sum of weighted inputs, where the input and output data are given. CRS measures the total efficiency of n DMUs, where each has s outputs sharing m inputs. Given x_{ij}, the value of input i for DMU j (for all $i = 1, \ldots, m$ and $j = 1, \ldots, n$), and y_{rj}, the past value of output r for DMU j (for all $r = 1, \ldots, s$), we solve n problems, one for each DMU. The problem, for DMU k, is to find v_{ik}, the optimal weight of input i, and u_{rk}, the optimal weight of output r for DMU k, for all i and r, which maximize its relative efficiency measure, h_{kk}, where

$$h_{kj} = \sum_{r=1}^{s} u_{rk} y_{rj} / \sum_{i=1}^{m} v_{ik} x_{ij} \tag{12.1}$$

(f) The problem, for DMU k, is

$$\max \quad h_{kk} \tag{12.2}$$

(g) subject to

$$h_{kj} \leq 1, \quad j = 1 \ldots n \tag{12.3}$$

$$\begin{aligned} &u_{rk}, v_{ik} \geq \varepsilon \\ &i = 1 \ldots m \\ &r = 1 \ldots s \end{aligned}$$

The relative efficiency is the ratio between the sum of weighted outputs and the sum of the weighted inputs. This ratio is in the range (0,1], since the data are positive, and their weights are non-negative (or limited by an infinitesimal value). If, with its ideal weights, DMU k does not receive the maximal efficiency score of 1 (100%), then DMU k is not efficient; i.e., other DMUs (or a combination of DMUs) received the maximal score of 1 with the ideal weights for DMU k. However, if DMU k receives the maximal possible efficiency rate of 1, then unit k is relatively efficient. CRS is named the *overall efficiency*. The last column of Appendix Table 12.8 presents CRS efficiency values for our case study. CRS is a deterministic method. Its limitation is the weights, which vary greatly from one

DMU to another (columns V1 till U3 in Appendix Table 12.8 for our example); thus, these efficiencies are not really comparable, although often are used as a rank scale (e.g., Andersen & Petersen, 1993); but Banker and Chang (2006) point out that CRS values are not a rank scale. In fact, CRS version of DEA provides a dichotomy of the DMUs into two groups: efficient and inefficient.

12.3.2 SE-CRS Method

According to the CRS version of DEA, all the efficient DMUs receive an efficiency value of 1. In order to allow for a range of values more than 1, Andersen and Petersen (1993) developed SE, and specifically the SE-CRS method, where efficient DMUs can receive efficiency values greater than 1, yet the values of inefficient DMUs are identical to CRS, namely less than 1. Thus, SE-CRS efficiencies provide a full scale which, unlike CRS, is not bounded at 1. For SE-CRS, the constraints of the optimization problem of the above CRS mathematical formulation for DMU k is not applied to constraint k; namely, in the above formulation the constraint (12.3) of $j = k$ is deleted. Thus, h_{kk} may exceed the efficiency value of 1 (as shown for our example in Table 12.2, first column). Nevertheless, it is problematic to use SE-CRS (like CRS) efficiencies as a comparable scale for all DMUs since the weights of the inputs and outputs vary greatly from one DMU to another. Basically, both CRS and SE-CRS provide a dichotomy of the units into two groups, efficient and inefficient. The efficiency of DMU k reflects the extent to which it fulfilled its own potential with its own ideal weights, in relation to other DMUs using the ideal weights for k. However, in practice many researchers use SE-CRS as a comparable rank scale, including its initiators, Andersen and Petersen (1993). Banker and Chang (2006) address this problem too.

12.3.3 VRS Efficiency Method

The VRS DEA efficiency method was developed by Banker et al. (1984). VRS formulation is almost identical to CRS, with the difference that a constant value, ω_k, is subtracted from the numerator of the objective function and the numerator of the constraints (the sum of weighted outputs). Efficient DMUs receive efficiencies of 1, while inefficient DMUs receive values less than 1, just like with CRS efficiency. Similarly, the weights, v_{ik} and u_{rk}, vary greatly from one DMU to another, and so does the constant, ω_k, where $\omega_k < 0$ reflects a decreasing return to scale, $\omega_k > 0$ reflects an increasing return to scale, and $\omega_k = 0$ reflects a constant return to scale (before the last column of Appendix Table 12.9). VRS efficiency is greater than, or equal to, CRS efficiency. VRS efficiency is called technical efficiency (also pure technical efficiency, and managerial efficiency). Just like CRS, VRS does not provide a rank scale for efficient DMUs, nor to inefficient DMUs, due

Table 12.2 Academic departments' various efficiencies and original data[a]

Department	SE-CRS Eff.	CE-CRS Eff.	Disc-CRS	Disc-VRS[b]	Canonical	X1	X2	Y1	Y2	Y3
Geography	1.514	0.866	0.877	0.856	1.479	108, 800	278,200	27, 900	48	3610
History	0.765	0.459	−1.412	0.596	0.678	133, 900	744,000	3430	57	6470
Education	2.536	0.859	3.107	1.704	1.044	169, 000	559,400	109, 890	35	6500
Economics	1.268	0.535	2.450	0.286	0.835	175, 700	570,100	2480	17	18, 960
Hebrew Lit.	0.892	0.455	−0.891	−0.378	0.524	62, 300	518,400	600	25	5120
Behavioral Sci.	1.115	0.677	2.065	1.364	0.919	140, 200	616,100	27, 200	38	13, 280
Bible	0.680	0.499	−0.835	−0.484	0.911	138, 700	341,000	14, 400	40	2390
Foreign Lit.	1.377	0.651	0.097	0.202	0.923	57, 800	341,500	270	33	5020
Social Work	0.729	0.486	−0.240	−0.676	0.732	59, 400	271,600	2900	19	3610
Philosophy	0.733	0.466	−0.340	−1.003	0.603	33, 100	197,000	3740	11	1930
Biology	0.703	0.470	−2.674	−2.274	0.786	658, 300	896,900	91, 060	77	7520
Geology	0.563	0.422	−1.241	−1.319	0.746	178, 000	340,400	21, 070	31	1990
Chemistry	0.882	0.610	−1.165	0.491	1.126	588, 600	801,100	74, 210	118	8350
Math.	1.133	0.596	4.348	2.761	1.091	411, 200	968,800	12, 120	75	31, 940
Physics	0.684	0.542	−1.109	1.264	0.934	464, 200	995,000	76, 570	108	8070
Nuclear Eng.	0.887	0.612	−0.483	−0.435	1.083	200, 800	332,800	33, 920	46	2300
Chemical Eng.	0.617	0.453	−1.673	−1.045	0.793	290, 500	540,300	38, 270	52	3270
Material Eng.	0.884	0.570	0.376	−0.488	0.972	275, 900	460,800	44, 590	41	7640
Electrical Eng.	0.693	0.362	−2.527	−3.356	0.711	585, 900	721,500	25, 220	49	13, 140
Mechanical Eng.	0.665	0.426	−1.435	−0.834	0.792	540, 100	994,400	38, 290	77	15, 630
Ind.Eng. & Mgmt	1.095	0.709	2.706	2.768	1.189	220, 000	694,800	18, 990	74	17, 330

[a]Data is taken from Sinuany-Stern et al. (1994). Though all the calculations here are original, there was a mistake (typo) in one of the original X1 figures for Nuclear Engineering, which is fixed here

[b]VRS efficient departments are the SE-CRS efficient departments plus four more: History, Philosophy, Chemistry, and Physics

to the variability of VRS weights and the fact that efficient DMUs each receive an efficiency value of 1.

12.3.4 SE-VRS Method

To provide a wider scale for VRS-efficient DMUs, above 1, SE, developed by Andersen and Petersen (1993), is applied also to VRS. In SE-VRS, for the optimization problem of DMU k, the ratio constraint k of the optimization problem in the VRS mathematical formulation is not applied. Thus, h_{kk} may exceed the efficiency value of 1 (as shown for our example in Appendix Table 12.9, last column).

The SE-VRS efficiency division into efficient and inefficient is identical to that for VRS efficiency. However, for efficient DMUs, VRS efficiency values are 1, while for SE-VRS they may exceed 1, thus allowing for a full scale; SE-VRS is not bounded at 1. However, it is problematic to use SE-VRS (and even VRS) efficiencies as a comparable scale, since the weights vary greatly from one DMU to another; this method has the same limitations as CRS, SE-CRS, and VRS, as discussed above. Moreover, SE-VRS efficiency values may often be infeasible (as shown in the last column of Appendix Table 12.9, for three departments), and so this method was not included in the robust analysis here. (Lee et al. (2011) suggested a resolution.) Banker and Chang (2006) also questioned the fitness of SE as a ranking method for the efficient DMUs (see also Zhu, 1996).

12.3.5 CE-CRS Cross-Efficiency Method

CE was developed by Sexton et al. (1986) and has often been used for scale-ranking (e.g., Doyle & Green, 1994; Ruiz & Sirvent, 2016). Beasley (1995) applied CE in HE. Cross-efficiency is based on the original DEA results, but implements a secondary stage where each DMU peer-appraises all other DMUs with its own factor weights. The average of these peer-appraisal scores is then used to calculate a DMU's CE. The CE score of each DMU is therefore assessed with the CRS weights of all the DMUs, instead of only its own weights (e.g., CRS weights in Appendix Table 12.8), which create a cross-efficiency matrix from which an average measure is calculated for the *kth* DMU as follows:

$$\overline{h_k} = \sum_{j=1}^{n} h_{jk}/n$$

Table 12.2 (second column) shows CE-CRS efficiency for the academic departments' example. The efficiencies of CE-VRS are not considered here, since the constant added to the outputs is not limited by sign, and so some of the cross-efficiency values may be negative and some are infeasible. Note that the issue of multiple solutions to the CRS weights was resolved by Oral et al. (1991). The scale range of CE is (0,1].

12.3.6 Disc-CRS Efficiency Method Based on Discriminant Analysis

Another approach to remedy some of DEA's drawbacks is stochastic DEA, which synthesizes DEA and stochastic frontier analysis (SFA). Some of SFA's variations are based on multivariate analyses such as discriminant (Disc) analysis. The Disc-CRS method is a multinomial statistical method, where the dichotomy of CRS into efficient (1) and inefficient (0) groupings is applied to the linear Disc model, which calculates the optimal common weights which reclassify the DMUs into efficient and inefficient with the best match to the original CRS classification, via a critical d^* value that discriminates between the two groups. The resulting Disc analysis scores, di, of the DMUs are their Disc-CRS efficiencies (Sinuany-Stern et al., 1994). We expect the weights of the Disc-CRS linear function to be positive for the outputs, and to be negative for the inputs (e.g., see common weights of Disc-CRS in Table 12.3). The values of Disc-CRS are not bounded, but in practice they vary between −4 and 4, with an average around zero (see Table 12.2 column Disc-CRS).

The advantage of Disc-CRS is that it uses the dichotomy of CRS into two groups, efficient and inefficient, and the common weights apply to all DMUs. Disc-CRS's limitation is that some of its output weights may be negative, or some of the input weights may be positive. In such cases Disc cannot be used—it is infeasible.

12.3.7 Disc-VRS Efficiency Method Based on Discriminant Analysis

The VRS efficient and inefficient grouping is applied to the linear Disc model, similarly to Disc-CRS but with a new VRS grouping. The resulting Disc of each DMU is its Disc-VRS efficiency (Sinuany-Stern & Friedman, 1998). Disc-VRS has the same advantages and disadvantages as Disc-CRS (see common weights of Disc-VRS in Table 12.3, and Table 12.2 column Disc-VRS).

Table 12.3 Discriminant and canonical analysis weights for the academic departments' case study

Variable	X1	X2	Y1	Y2	Y3
Discriminant-CRS	−1.8586	−1.1989	1.3077	0.5646	2.5359
Discriminant-VRS	−2.2846	−0.1935	0.7472	1.4829	1.2785
Canonical	1.2997	3.0880	7.7256	21,257.0600	67.5641

12.3.8 CCA—Canonical Correlation Efficiency Method

Canonical correlation analysis (CCA) is a multivariate statistical method, another form of SFA which finds weights for two groups of variables (inputs and outputs in our case), which maximize the correlation between the sum of the weighted outputs and the sum of the weighted inputs. CCA efficiency is the ratio between the sum of the weighted outputs and the sum of the weighted inputs (Friedman & Sinuany-Stern, 1997). The advantage of CCA is that it has one common set of weights for all DMUs, and thus their efficiencies are comparable (e.g., common weights of canonical in Table 12.3). Note that CCA is not based on the DEA dichotomy. Thus, CCA weights are independent of DEA, although both efficiencies are defined similarly, as the ratio between the weighted sums of the outputs and the inputs. However, while DEA (CRS and VRS versions) provides the efficient frontier, CCA is a sort of extended regression that finds the weights which maximize the correlation between the weighted outputs and the weighted inputs. Thus, such a method, which is independence of DEA-based methods is important (Table 12.2). The scale range of feasible CCA in the DEA context is $(0,\infty)$—if any CCA weight turns negative then CCA cannot be used in the DEA context, as it is infeasible in this case; since, positive input cannot contribute negatively to the overall sum of weighted inputs, and positive output cannot contribute negatively to the overall sum of weighted outputs.

12.3.9 REG—Regression SFA

Regression efficiency (REG) is another form of SFA model. REG can be used if there are one input and multiple outputs (or one output and multiple inputs). When there is one input, and the error of DMU j is positive (i.e., above the regression predictor), it means that DMU j used more input than average. Thus, the higher the error the lower the efficiency, and so the opposite error sign is used as an efficiency value (as shown in the last two columns of Appendix Table 12.11). When there are one output and multiple inputs then the error is used as-is, so when the error is positive (i.e., above the average expected output for the given inputs), the efficiency is higher when the error is higher. The REG method is feasible and can be used only if all the variables' coefficients are positive (as shown in Appendix 6). In this case, where REG is possible, discriminant analysis and canonical correlations are redundant.

12.3.10 Evaluation of the Efficiency Methods

There are many more efficiency methods (see Adler et al., 2002; Hosseinzadeh-Lotfi et al., 2013; Sueyoshi, 1999). We tried, in our case study, to cover a large variety of efficiency methods. Only five of the efficiency methods described above were finally used for rank scaling of efficiencies. We presented SE rather than the original DEA efficiency methods (CRS and VRS), since SE uses the same scale as DEA for the inefficient DMUs, but extends the scale of the efficient DMUs beyond the value 1 (while all efficient DMUs get the value 1 under CRS and VRS). Thus, CRS and VRS are redundant. SE-VRS was not used as an efficiency method in our case study since some of the super efficiencies were infeasible, but we used VRS as the dichotomy for the Disc-VRS efficiency method. Since the first four DEA and SE methods do not provide rank scales, as they are not based on common weights, they are not comparable. Their weights vary greatly from one DMU to another. We used CE-CRS efficiency, which provides a full efficiency scale based on the weights of all DMUs for the evaluation of each DMU. CE-VRS was not used, since for some DMUs within the calculation of CE, some values are negative due to the negative constants in some of the CE values using VRS weights. The better known multivariate statistical methods for rank scaling were also used: discriminant analysis based on the DEA dichotomy for CRS and for VRS classification of DMUs into efficient and inefficient groups, and the canonical correlation method. These two methods are based on common weights and are adapted to the DEA structure of data with multiple inputs and multiple outputs. As summarized in Table 12.1, these five efficiency methods were selected. In Sect. 12.6, we used the sum of the inputs as one variable, X1 + X2. Thus, we used REG as one of the efficiency methods.

12.4 The Case Study

The case study for exemplifying the robust efficiency is taken from Sinuany-Stern et al. (1994), including 21 academic departments within a university, based on two inputs and three outputs.

The two inputs are:

X1—operational costs
X2—faculty salaries
The three outputs are:
Y1—grant money
Y2—number of publications
Y3—contact hours given by the department

The input and output data for X1, X2, Y1, Y2, and Y3 is given in the last five columns of Table 12.2. Note that we do not include the original output "number of graduate students" since one department had no graduate students, and three other departments had one graduate student at that time. Moreover, in the original paper there was a mistake (typo) in the data: for the Department of Nuclear Engineering's "operational costs," the value 2005,800 is written, while it was actually 200,800 (although all the calculations were performed with the correct figure there). Consequently, all the tables and the appendices here are original to our paper. Descriptive statistics are given in Appendix Table 12.7. For DEA and efficiency runs we transformed the data so that the maximal value of each column (variable) was 100. Thus, the weights of the variables are comparable.

12.5 Results of Academic Department Efficiencies

Table 12.2 provides the efficiency scales of the five methods finally selected. Table 12.2 reveals that seven departments were CRS and SE-CRS efficient, and 11 departments were VRS and SE-VRS efficient, of which three departments had infeasible SE-VRS values. The CE-CRS range was between 0.362 and 0.866. Note that, in comparison to the basic results from the original paper (Sinuany-Stern et al., 1994), where only CRS efficiency was used, the exact same seven departments turned out to be efficient, even though one output was dropped in the current study. The CRS efficient departments are Geography, Education, Economics, Behavioral Sciences, Foreign Literature, Mathematics, and Industrial Engineering. VRS efficiency was not run in the previous article; we ran it here, and found an additional four efficient departments—History, Philosophy, Chemistry, and Physics—for a total of eleven VRS-efficient departments (see footnote[b] in Table 12.2).

The discriminant analysis weights for CRS and VRS dichotomies are negative for the inputs and positive for the outputs, as expected in the DEA context; Disc-CRS and Disc-VRS efficiencies are feasible here (see Table 12.3 for the weights, and Table 12.2 for the efficiencies). Note that the efficiencies of both, Disc-CRS and Disc-VRS, always have negative and positive values (between -4 and $+4$), as explained in Sects. 12.3.6 and 12.3.7, respectively.

Similarly, the weights of the canonical correlation are positive, as expected in the DEA context, and so the CCA efficiency method is feasible here (see Table 12.3 for the weights, and Table 12.2 for the efficiencies). Note that always the efficiencies of CCA are positive, as explained in Sect. 12.3.8. Moreover, in our case study, the canonical correlation is very high (0.9082) and significant at less than 0.01 p-value.

12.5.1 Choosing the Robust Efficiency Method

The upper diagonal of Table 12.4 presents the Pearson correlations between the efficiencies of pairs of the above five methods, which vary here between 0.4836 and 0.8297, where most of the correlations are statistically significant as shown in Table 12.4, most of them with p-values less than 0.01.

Table 12.5 presents the average of the sum of Pearson correlations for each efficiency method. Obviously, the CE-CRS method provides a robust solution—its average correlation with other methods has the maximal value - 0.7558.

Table 12.4 Pearson (upper diagonal) and Spearman correlations among efficiency methods[a]

Pearson: Spearman:	SE-CRS	CE-CRS	Disc-CRS	Disc-VRS	CCA
SE-CRS		0.8297^{*}	0.6797^{*}	0.5320^{***}	0.4836^{***}
CE-CRS	0.7870^{*}		0.6736^{*}	0.6981^{*}	0.8218^{*}
Disc-CRS	0.7974^{*}	0.7610^{*}		0.8087^{*}	0.4937^{***}
Disc-VRS	0.6987^{*}	0.7701^{*}	0.7260^{*}		0.5769^{***}
CCA	0.5026^{**}	0.8351^{*}	0.5571^{*}	0.6429^{*}	

$^{*}p < 0.01$, $^{**}p < 0.05$, $^{***}p < 0.1$
[a]CRS—constant return to scale; VRS—variable return to scale; SE—super efficiency; CE—cross-efficiency; Disc—discriminant analysis; CCA—canonical correlation

Table 12.5 The average correlation of each efficiency model with the other models

Model type	Average of Pearson correlations with other methods	Average of Spearman rank correlations with other methods
Super Efficiency CRS	0.6312	0.6964
Cross-Efficiency CRS	**0.7558**	**0.7883**
Discriminant CRS	0.6639	0.7103
Discriminant VRS	0.6535	0.7094
Canonical Correlation	0.5940	0.6344

12.5.2 Robustness for Ranks of the Efficiencies

Appendix Table 12.10 provides a full ranking for each of the five efficiency methods, which follows from ordering the efficiencies of each method in Table 12.2. The lower diagonal of Table 12.4 presents the Spearman rank correlations between the efficiencies of pairs of the above five efficiency methods. For Spearman rank correlations, 9 out of 10 correlations were significant with p-value less than 0.01, and the tenth significance is 0.02. The average of the Spearman rank correlations of each efficiency method with the other methods is given in Table 12.5. Clearly, the cross-efficiency method again has the highest value, namely 0.7883. Thus, CE-CRS is the robust solution. The identical conclusion from the Pearson and Spearman average correlations strengthens the robustness of the choice of CE-CRS as the efficiency of the academic departments in this study. Looking at CE-CRS efficiencies in Table 12.2 shows that the number 1 most efficient department in this case study is Geography, with CE-CRS efficiency of 0.866. But the lowest-ranked department via the robust solution CE-CRS is Electrical Engineering in this case study (ranked last—21).

For further verification, testing with the Friedman nonparametric ANOVA test for ranks, we conclude that we cannot reject the hypothesis that the five ranks are similar (chi-square statistic with 4 d.f. is 0.6952, $p = 0.95$). Thus, we conclude that the ranks of the five efficiency methods are significantly similar. The robust method is CE-CRS.

12.6 One Input and Three Outputs—Regression Efficiency

Since the two inputs X1 and X2 are monetary values, which can be added up, the sum of the inputs X1 + X2 = SX can be taken as one input versus the three original outputs. For this case, in addition to the DEA efficiency, we can take the multiple regression model of SX as a linear combination of the three outputs. The REG value is the negative of the regression error. The results of the parameters of the regression model coefficients are given in Appendix 6. All the regression coefficients are positive, and so REG is a feasible efficiency method.

In this case, where regression analysis is possible, discriminant analysis and canonical correlations are redundant. Regarding SE-VRS* for the case of one input SX, as shown in Appendix Table 12.11 (second column), three DMUs are infeasible, so again SE-VRS* was not used. Only SE-CRS*, CE-CRS*, and REG were feasible and used.

Looking at the correlations of the case with one input (X1 + X2) in Table 12.6, by the criterion of the average of the relevant Pearson correlations, all of them are highly significant ($p < 0.01$), in this case with one input,

For SE-CRS*, the average Pearson correlation is 0.7128 = (0.8224 + 0.6032)/2.
For CE-CRS*, the average Pearson correlation is 0.8124 = (0.8224 + 0.8024)/2.
For REG, the average Pearson correlation is 0.7028 = (0.6032 + 0.8024)/2.

Table 12.6 Pearson/Spearman[a] correlations among efficiency methods for X1, X2, and X1 + X2

	SE-CRS	CE-CRS	SE-CRS[b]	CE-CRS[b]	REG
SE-CRS		0.8297	0.9546	0.7044	0.5337
CE-CRS	0.7870		0.8656	0.9434	0.8191
SE-CRS[b]	0.7636	0.8753		0.8224	0.6032
CE-CRS[b]	0.6312	0.9130	0.9039		0.8024
REG	0.6260	0.8922	0.7701	0.8610	

[a]Pearson values are above the diagonal, while Spearman values are below the diagonal. CRS—constant return to scale; SE—super efficiency; CE—cross-efficiency; REG—regression efficiency
[b]One input (X1 + X2)

Obviously, the greatest average Pearson correlation is again achieved with CE-CRS* (0.8124) as a robust solution, as was the case in Sect. 12.5.1 for CE-CRS.

Looking at the Spearman rank test (below the diagonal in Table 12.6), again all the correlations are highly significant ($p < 0.01$). For the case of one input,

For SE-CRS*, the average Spearman correlation is 0.8370.
For CE-CRS*, the average Spearman correlation is 0.8824.
For REG, the average Spearman correlation with the other two methods is 0.8155.

Consequently, the greatest average Spearman correlation is again achieved with CE-CRS* (0.8824) as a robust solution, as was the case in Sect. 12.5.2 for CE-CRS.

Using the regression model did not change the robust solution, although all the correlations were significant. Using Friedman nonparametric ANOVA, for the three rankings of the efficiencies for the case of one output: SE-CRS*, CE-CRS*, and REG, the chi-square value is 0.2143 (d.f. 2,21), with $p = 0.8984$, so the null hypothesis that the methods' ranks are similar cannot be rejected.

Overall, looking at the case where two inputs are considered and the case where the two inputs are added into one input (X1 + X2), we see that the department which was closed, Nuclear Engineering, was ranked between sixth and ninth out of 21 departments, although under the cost per student model (Sinuany-Stern et al., 1994) it was the worst and thus was closed. We now know that Nuclear Engineering department was reopened a few years later, based on academic reasoning rather than economic considerations. The Geology department, which was recommended to be closed then due to its high cost per student, is ranked here between 14th and 20th.

12.7 Conclusion

Once several efficiency methods are used in a specific application, the robust method suggested here is to calculate the correlations of all pairs of efficiency scales, then to calculate for each efficiency method its average correlations with all other efficiency methods. The robust efficiency method is the one with the maximal average efficiency. The nonparametric Friedman ANOVA is also used to verify the fit between the various efficiency methods.

Our analyses of the case of academic departments exemplify the need to use multiple inputs and multiple outputs (including academic outputs), as was done in our case. In measuring the efficiency in general, and in higher education in particular, multiple efficiency methods may provide a robust solution that is best correlated with a group of other efficiency methods. With the development of further new efficiency methods (e.g., De Witte & Lopez-Torres, 2017; Hosseinzadeh-Lotfi et al., 2013; Liu & Peng, 2008; Olsen & Petersen, 2016; Pino-Mejías & Luque-Calvo, 2021), this method of robust efficiency is very important to allow practitioners to verify the robust solution. It is also important to realize that, in practice, some of the multivariate statistical methods may be infeasible for the data used, due to an inappropriate sign in some of the weights; for example, negative coefficients in some of the variables for regression or canonical correlation.

Appendix 1

Table 12.7 Descriptive statistics for inputs and outputs of academic departments

Variables[a]	Min	Median	Mean	Max	SD
X1	197, 000	559, 400	580, 195	995, 000	254,100
X2	33, 100	178, 000	261, 543	658, 300	197,954
X1 + X2	230, 100	745, 800	841, 738	1, 555, 200	427,807
Y1	270	25, 220	31, 768	109, 890	31,598
Y2	11	46	51	118	28.37
Y3	1930	6500	8765	31, 940	7418

[a] X_i is input i, Y_r is output r

Appendix 2

Table 12.8 CRS weights (prices) of inputs and outputs for academic departments

Weights: Department:	V1	V2	U1	U2	U3	CRS Eff[a].
Geography	0.060	0	0.010	0.018	0	1.000
History	0.049	0	0.007	0.015	0	0.765
Education	0.039	0	0.010	0	0	1.000
Economics	0.037	0	0	0	0.017	1.000
Hebrew Lit.	0.106	0	0.005	0.008	0.045	0.892
Behavioral Sci.	0.022	0.009	0.006	0.005	0.017	1.000
Bible	0	0.030	0	0.020	0	0.680
Foreign Lit.	0.068	0.012	0	0.036	0	1.000
Social Work	0.068	0.014	0.013	0.020	0.033	0.729
Philosophy	0.199	0	0.030	0.027	0.063	0.733
Biology	0	0.011	0.005	0.005	0	0.703
Geology	0	0.029	0.013	0.012	0	0.563
Chemistry	0	0.012	0.006	0.005	0	0.882
Math.	0.007	0.006	0	0.003	0.008	1.000
Physics	0	0.010	0.004	0.004	0	0.684
Nuclear Eng.	0	0.030	0.013	0.012	0	0.887
Chemical Eng.	0	0.018	0.008	0.008	0	0.617
Material Eng.	0	0.022	0.007	0.006	0.016	0.884
Electrical Eng.	0	0.014	0.004	0.004	0.011	0.693
Mechanical Eng.	0	0.010	0.003	0.003	0.008	0.665
Ind.Eng. & Mgmt	0.020	0.005	0	0.005	0.012	1.000

[a]CRS Eff.—cross efficiency

Appendix 3

Table 12.9 VRS weights (prices) of inputs (Vi) and outputs (Ur) for the academic departments

Dept./ weights	V1	V2	U1	U2	U3	Constant ω	SE-VRS Eff.[a]
Geography	0.060	0	0.010	0.018	0	0	1.540
History	0.046	0.001	0	0.028	0	0.346	1.100
Education	0.039	0	0.010	0	0	0	Inf
Economics	0.037	0	0	0	0.017	0	1.268
Hebrew Lit.	0.106	0	0.006	0	0.043	−0.306	0.943
Behavioral Sci.	0.020	0.009	0.005	0.005	0.015	−0.080	1.152
Bible	0	0.029	0	0.008	0.000	−0.743	0.764
Foreign Lit.	0.022	0.023	0	0.010	0.024	−0.335	1.381
Social Work	0.026	0.028	0	0.012	0.029	−0.478	0.920
Philosophy	0	0.050	0	0	0	−1.000	1.821
Biology	0	0.011	0.004	0.005	0.008	−0.156	0.759
Geology	0	0.029	0.011	0	0	−0.792	0.750
Chemistry	0.008	0.004	0.004	0.010	0	0.280	Inf
Math.	0.007	0.006	0.000	0.003	0.008	0	Inf
Physics	0.014	0	0.003	0.012	0	0.343	1.151
Nuclear Eng.	0	0.030	0.011	0	0	−0.650	0.898
Chemical Eng.	0	0.018	0.008	0.010	0	−0.251	0.630
Material Eng.	0	0.022	0.006	0.002	0.017	−0.253	0.908
Electrical Eng.	0	0.014	0.004	0.001	0.011	−0.394	0.708
Mechanical Eng.	0	0.010	0.004	0.004	0.007	−0.226	0.697
Ind.Eng. & Mgmt	0.027	0.001	0	0.017	0.003	0.250	1.412

[a]SE-VRS Eff.—super efficiency variable return to scale

Appendix 4

Table 12.10 Rankings of the academic departments via five efficiency methods[a]

Department	SE-CRS	CE-CRS	Disc-CRS	Disc-VRS	CCA
Geography	2	1	6	6	1
History	12	16	17	7	19
Education	1	2	2	3	6
Economics	4	11	4	9	12
Hebrew Lit.	8	17	13	11	21
Behavioral Science	6	4	5	4	10
Bible	18	12	12	13	11
Foreign Lit.	3	5	8	10	9
Social Work	14	13	9	15	17
Philosophy	13	15	10	17	20
Biology	15	14	21	20	15
Geology	21	20	16	19	16
Chemistry	11	7	15	8	3
Math.	5	8	1	2	4
Physics	17	10	14	5	8
Nuclear Eng.	9	6	11	12	5
Chemical Eng.	20	18	19	18	13
Material Eng.	10	9	7	14	7
Electrical Eng.	16	21	20	21	18
Mechanical Eng.	19	19	18	16	14
Ind.Eng. and Mgmt	7	3	3	1	2

[a]CRS—constant return to scale; VRS—variable return to scale; SE—super efficiency; CE—cross-efficiency; Disc—discriminant analysis; CCA—canonical correlation

Appendix 5

Table 12.11 Efficiencies where input is X1 + X2 for academic departments

Department	SE-CRS[a]	SE-VRS[a]	CE-CRS[a]	REG	REG-Ranking
Geography	1.452	1.452	0.939	18.934	1
History	0.591	0.621	0.436	−8.792	17
Education	2.093	inf	0.824	12.332	3
Economics	1.098	1.183	0.571	−3.027	15
Hebrew Lit.	0.498	0.627	0.355	−9.577	18
Behavioral Sci.	0.893	0.913	0.649	4.367	8
Bible	0.672	0.736	0.553	3.857	9
Foreign Lit.	0.838	0.963	0.600	6.168	7
Social Work	0.641	0.914	0.480	1.456	11
Philosophy	0.515	1.447	0.414	1.266	12
Biology	0.547	0.682	0.483	−20.799	20
Geology	0.511	0.644	0.458	−2.624	14
Chemistry	0.705	inf	0.648	9.482	4
Math.	1.044	inf	0.688	9.267	5
Physics	0.644	0.890	0.588	−0.278	13
Nuclear Eng.	0.762	0.769	0.653	7.756	6
Chemical Eng.	0.553	0.589	0.488	−5.697	16
Material Eng.	0.756	0.764	0.616	2.467	10
Electrical Eng.	0.537	0.542	0.407	−25.795	21
Mechanical Eng.	0.606	0.656	0.483	18.679	19
Ind.Eng. and Mgmt	1.031	1.129	0.767	17.915	2

CRS—constant return to scale; SE—super efficiency; CE—cross-efficiency; REG—regression efficiency

[a]Efficiencies for the case of one input, X1 + X2

Appendix 6: The Regression Results for Calculating Regression Efficiency

$X = X1 + X2$ is the dependent variable; Y1, Y2, and Y3 are the explanatory variables.

The F-statistic shows a very significant fit, as shown in the last line under the table.

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   6.3862     6.2265   1.026  0.31943
Y1            0.2406     0.1253   1.921  0.07172 .
Y2            0.6350     0.1570   4.046  0.00084 ***
Y3            0.4860     0.1371   3.544  0.00249 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 12.87 on 17 degrees of freedom
Multiple R-squared:  0.8141,    Adjusted R-squared:  0.7813
F-statistic: 24.81 on 3 and 17 DF,  p-value: 1.929e-06
```

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Part III
Applications

Chapter 13
Course Evaluation Using Preference Disaggregation Analysis: The Case of an Information Communication Technology Course

Ioannis Sitaridis, Fotis Kitsios, Stavros Stefanakakis, and Maria Kamariotou

Abstract The purpose of this chapter is to evaluate students' satisfaction attending an Information Communication Technology (ICT) course. An adapted version of the Course Experience Questionnaire (CEQ) was used in order to evaluate students' satisfaction, based on their experience. The 36-item scale includes measures for Good teaching, Clear Goals, Appropriate Workload, Appropriate Assessment, and Independence in Learning and development of Generic Skills. The data were analyzed using preference disaggregation analysis, a method of multiple criteria analysis, based on the principles of ordinal regression. The findings of this chapter provide many practical implications for educators because they can identify the strengths and weaknesses of the course. Therefore, they can improve teaching weaknesses based on students' satisfaction rates. Additionally, the methodology that was used will provide curriculum designers with a tool in order to evaluate their current courses and will support them to incorporate improved educational approaches in the future. Multi-criteria decision analysis offers many benefits for education practitioners, such as the identification of problems as well as the opportunity to prioritize the necessary interventions for improving their teaching. Last but not least, this method supports educators to organize the course more flexibly and facilitate students communicate with teachers and participate more actively in the educational process.

Keywords Course evaluation · Multi-criteria analysis · Disaggregation analysis · Satisfaction · ICT course

I. Sitaridis · F. Kitsios · S. Stefanakakis · M. Kamariotou (✉)
Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece
e-mail: ysitar@uom.edu.gr; kitsios@uom.gr; mkamariotou@uom.edu.gr

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13.1 Introduction

Students' satisfaction became part of universities' mission statement and was used as a marketing strategy, since these institutions have to operate in an environment where competitiveness is continuously increased, making it more and more difficult to justify their role and attract customers, i.e., students (Elliott & Shin, 2010). Students' satisfaction, nowadays, attracts research interest and it is used as a means of measuring course quality as it provides many advantages (Waugh, 1998). Satisfied students will dedicate more time and attention to their courses, and consequently, they carry out better in their classes. Furthermore, they strengthen their interpersonal interactions with their fellow students and professors. In addition, students attending courses that satisfy them tend not to dropout often (Gibson, 2010).

Certain dimensions of teaching are positively connected to student satisfaction, such as effective teaching, independent learning, and development of skills during the course (Law & Meyer, 2011a). Finally, an equally important dimension related to students' satisfaction is whether or not the academic staff is capable of responding adequately to the needs of students (Gibson, 2010; Kitsios & Sitaridis, 2017; Sitaridis & Kitsios, 2016a, 2016b, 2017). On the other hand, the assessment of educational programs is substantial for their success and the quality of learning outcomes. Students' experience can be used as a measure of the overall quality of the course as well as, the performance of teaching. The quality of educational courses can be implicitly evaluated by participating students, based on their judgments regarding various dimensions of teaching. Students' judgments may highlight course strengths and weaknesses, and providing data on the teaching quality. Educators and curriculum designers can benefit from this kind of diagnostic information (Sitaridis et al., 2018; Sitaridis & Kitsios, 2019a).

Student experience evaluation is used by course designers in order to improve their courses. However, the main difficulty with such evaluations is that the measures are mostly descriptive, without giving insight, in order for educators to prioritize them and organize interventions in accord. Thus, Multi-Criteria Decision Making (MCDM) can offer a solution to the problem.

The MUlti-criteria Satisfaction Analysis (MUSA) has never been applied to assess academic courses before. The combination of Course Experience Questionnaire (CEQ) with multi-criteria analysis offers many advantages for course evaluation. Educators could be knowledgeable about the dimensions that are the main weaknesses based on students' perceptions, so as to improve them in order to increase the quality of their course as this method helps educators to take certain actions in order to do so.

In the Marketing and Operations Research field, MCDM methods, based on global and partial customer satisfaction measures, such as the MUSA are used for highlighting the strong and weak points of a product or service. In our case, the judgments of students are used for the assessment of an educational course. The case of an ICT course is examined as an example for the implementation of the suggested methodology, in order to measure the course quality and identify its strengths and weaknesses. For that purpose, an adapted version of the Course Experience Questionnaire (CEQ) is used in order to evaluate students' satisfaction using dimensions of teaching. The data were analyzed using MUSA method. The methodology uses students' expressed preferences evaluations as indices of their level of satisfaction.

The findings of this study contribute beneficial implications about the course performance, and the partial and total students' satisfaction with reference to the criteria and the importance of each one. The combination of CEQ with MUSA offers many advantages for course assessment. Firstly, all the criteria are taken into account simultaneously, using weights of relative importance calculated for each criterion. Secondly, the resulting value function shows how demanding the students are and the action diagrams illustrate the relations between criteria performance and importance. Finally, partial satisfaction functions also indicate the participants' degree of demand regarding each one of the criteria separately.

In contrast to previous studies, this study offers an extended review of the literature regarding the application of the CEQ, and the findings along with difficulties met in the various approaches. Especially, in this chapter, a full deployment of the MUSA method is presented, with more details given on the aggregation function and the calculation of weights. Whereas in Sitaridis et al. (2018), only the global satisfaction function is illustrated, being used to give information on the global demand of students, the Partial Satisfaction Functions are calculated, as well, providing information on students' demand on each distinct criterion separately. The Relative Action Diagram is thoroughly discussed and the analysis is reinforced with the Relative Improvement Diagram which can support decision-making, based on the effectiveness of possible interventions according to students' demand on each criterion. Finally, although the proposed methodology is conducted on a sample of secondary education students, this chapter offers a great opportunity for a comprehensive comparison between the results of other studies, not only in higher, but in secondary education, as well, a factor not available in previous works. The conclusion is reinforced with many arguments on the benefits of the proposed methodology, both in secondary and in higher education.

The rest of the chapter is structured as follows. Section 13.2 presents the theoretical background regarding previous studies that have used the Course Experience Questionnaire in order to evaluate courses based on students' perceptions. Section 13.3 describes the basic principles of MUSA method, the sample of the survey, and the development of Course Experience Questionnaire. Section 13.4 presents the analysis of the results applying MUSA method. Finally, Sect. 13.5 concludes the paper and presents practical implications and suggestions for further research.

13.2 Theoretical Background

13.2.1 The Course Experience Questionnaire

The CEQ was developed at Lancaster University in the 1980s in order to evaluate teaching in higher education (Wilson et al., 1997). The original questionnaire measured the performance of a course, taking into account students' perceptions on six different dimensions of teaching, namely, teaching quality, lucidity of goals, appropriate workload, appropriate evaluation methods, development of generic skills, and independence in learning. The rationale behind this approach is that, students' assessment is considered to be valid in order to predict learning outcomes, when it is positively related to their achievements (Ramsden, 1991, p. 132). In Australia, the CEQ has been used to provide universities with data regarding the perceived quality of degree programs, based on students' evaluation and help them to make useful comparisons in order to improve teaching quality standards (Griffin et al., 2003). Hence, there are many benefits to the use of this questionnaire for diagnostic purposes and evaluation (Ramsden, 1991, 2003). However, it received some criticism when it was used as a tool for management intervention in the evaluation of teaching (Talukdar et al., 2013). The questionnaire was updated by Wilson et al. (1997) in order to examine teaching quality, as well as the fundamental dimensions of improved learning. The reliability of the CEQ as a measure of teaching quality and course performance has been substantiated by numerous researches (Byrne & Flood, 2003; Law & Meyer, 2011b; Ramsden, 1991; Stergiou & Airey, 2012; Wilson et al., 1997) with exceptional results.

The CEQ has been used for measuring the students' satisfaction by several studies in higher education. Lyon and Hendry (2002) used the CEQ in order to examine teaching improvement in a graduate course of Australian graduate students. Grace et al. (2012) extended the CEQ adding an overall satisfaction dimension to it, in order to incorporate satisfaction measures in the original one. The analysis of the data, also conducted using a sample of Australian bachelor students, resulted in a six-factor model. Additionally, a modified version of the CEQ has been successfully used for the evaluation of tourism management courses in Greece by Stergiou and Airey (2012), using the structured equation modeling technique. The items examining Independence in learning were substituted with a generic scale examining the academic environment. All scales, except academic environment, exhibited high reliability, which resulted in a five-factor model. The main drivers for students' satisfaction proved to be "good teaching" and "clarity of goals." Rahman et al. (2012) used the CEQ in a tertiary education Engineering course, to associate course learning environment with students' learning approaches. The multiple regression analysis, highlighted good teaching and assessment as the main contributors to students' deep learning approach.

The CEQ was only recently used in higher secondary education for the assessment of Science courses (Chakrabarty et al., 2016). The confirmatory factor analysis resulted in a 4-factor solution. Significant correlations of all factors were found to the overall satisfaction item. The authors proposed the use of a reduced version of the questionnaire that includes 30 items, for future research.

To sum up, the main difficulties which were met when using regression analyses with the CEQ are that the total satisfaction measure does not often suit the framework and that the six-factor model is not confirmed in different contexts. The first difficulty arises from the fact that the overall satisfaction is conceptually different from all the other measures of the questionnaire, resulting in problematic model fit (Waugh, 1998). The second difficulty may be the result of the reduced number of items measuring each construct, affecting the reliability of the scale (Chakrabarty et al., 2016). Therefore, the frequent approach of using a single item for evaluating satisfaction is practically deficient for adequate statistical representation of the construct (Elliott & Shin, 2010; Grace et al., 2012). Furthermore, the scale was not originally designed for measuring students' satisfaction but the overall satisfaction item was added in order to validate students' satisfaction rather than measure it (Ramsden, 1991, 2003). Therefore, the correlations between the constructs of the CEQ and students' satisfaction do not have sufficient theoretical support required for regression analysis (Sitaridis & Kitsios, 2019b). For example, Stergiou and Airey (2012) wonder why specific CEQ constructs correlate with overall satisfaction, while others do not. Additionally, researchers use the CEQ for students' satisfaction, out of necessity, due to the lack of alternative scales (Grace et al., 2012). Finally, the relation of the anticipated course performance to proper resource allocation remains uncertain (Ramsden, 1991). What can be the solution to these problems is the analysis of CEQ data using means of multi-criteria analysis.

13.3 Methodology

The 36 items of the CEQ used in this chapter were adapted in order to measure students' satisfaction concerning six aspects of teaching. In detail, the adapted questionnaire involve items about Good teaching (8 items), e.g., "How satisfied are you with the staff effort to motivate you to do your best," Clear Goals (5 items), e.g., "How satisfied are you with the level of the difficulty in discovering what was expected from you," Appropriate Workload (4 items), e.g., "How pleased are you with the level of workload during the course," Appropriate Assessment (7 items), e.g., "How satisfied are you with the need to memorize things in order to do well," Generic Skills Development (6 items), e.g., "How satisfied are you with the contribution of the course in developing your ability to work in a team setting" and Emphasis on Independence in Learning (6 items), e.g., "How satisfied are you with the opportunities offered in this course to choose the areas of study." All items examine students' satisfaction on one of the six aspects of teaching examined by the original CEQ. A partial satisfaction item was added for each dimension of the CEQ, as well as an item measuring the overall satisfaction from the course.

Each one of the six aspects of teaching that were examined by the original CEQ, which appears in Fig. 13.1, consists of a distinct criterion of students' satisfaction

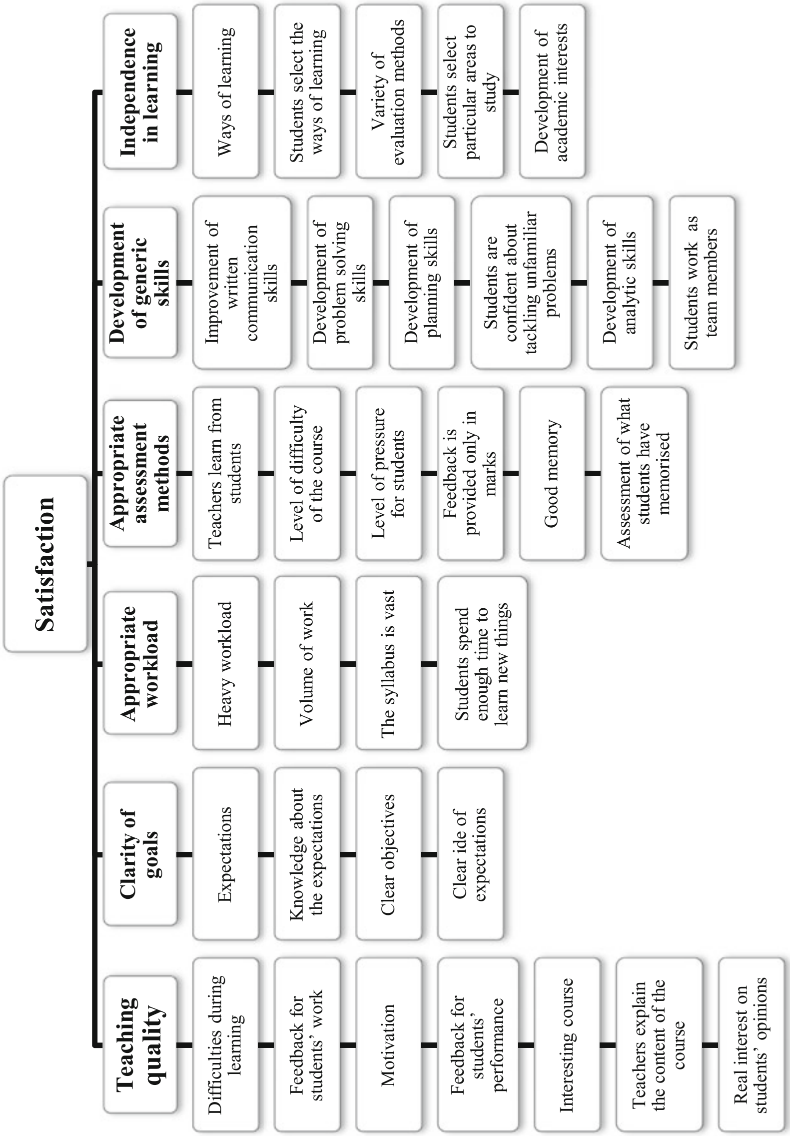

Fig. 13.1 Satisfaction criteria examined by the adapted questionnaire

in the adapted questionnaire. Each item of the original questionnaire was adapted in order to measure the extent of students' satisfaction on the corresponding criterion, for the purpose of this research. The adapted questionnaire items are presented in full detail in the Appendix 1, next to the corresponding item of the original CEQ.

13.3.1 Sample

All data were obtained from 125 first and second grade high school students participating in a public senior high school in Northern Greece. All students attended an ICT course and were requested to assess it based on the following criteria: teaching quality, consistency of goals, appropriate workload, appropriate evaluation methods used, independence in learning, and generic skills development during the course. The original 36 items of the CEQ were all used to measure students' satisfaction and were translated into Greek. Partial satisfaction questions were also added as per the requirements of MUSA. All constructs are assumed to be separate factors presenting various aspects of students' satisfaction. Each dimension has a mandatory partial satisfaction question at the end. Finally, there is a complete satisfaction question about the overall course evaluation.

13.3.2 The MUSA Method

MUSA was used to assess the satisfaction of students. This method can show the satisfaction indices of every criterion as just as the weights that students assess for every criterion (Kamariotou et al., 2018; Kitsios et al., 2009, 2015, 2016; Kitsios & Grigoroudis, 2016; Sitaridis et al., 2018; Stefanakakis et al., 2017; Stefanakakis & Kitsios, 2016). This method is utilized for the assessment of a set of marginal satisfaction functions. The global satisfaction function originates from the consequence of the marginal satisfaction functions that product customer feedback. The most significant goal of the method is thus the aggregation of individual decisions into a collective value function (Grigoroudis et al., 2000; Grigoroudis & Matsatsinis, 2018; Siskos et al., 1998).

The MUSA approach evaluates global and partial satisfaction functions $Y*$ and X_i^*, respectively, given consumers' ordinal judgments Y and X_i (for the i th criterion). The hypothesis of an added utility model is the basic axis of the method, and it is represented by the following ordinal regression analysis equation:

$$\check{Y}^* = \sum_{i=1}^{n} b_i X_i^* - \sigma^+ + \sigma^-$$

$$\sum_{i=1}^{n} b_i = 1$$

where $\check{Y}*$ is the estimation of the global value function Y^*, n is the number of criteria, b_i is a positive weight of the i th criterion, σ^+ and σ^- are the overestimation and the underestimation errors, respectively, and the value functions Y^* and $X_i^*$are normalized in the interval [0, 100] (Grigoroudis & Siskos, 2002, 2010).

The eventual outcome is determined utilizing the average of the near optimal solutions of linear programming, which aims to minimize the sum of errors based on the following constraints:

- Ordinal regression equation for each student.
- Normalization constraints for Y^* and X_i^* in the interval [0, 100], which can be written as follows:

$$y^{*1} = 0, y^{*a} = 100$$

  - $x_i{}^{*1} = 0, x_i{}^{*a_i} = 100$ for $i = 1, 2, \ldots, n$, where y^{*m} is the value of the y^m satisfaction level, x_i^{*k} is the value of the x_i^k satisfaction level

- Monotonicity constraints for Y^* and X_i^*:
  - $y^{*m} \le y^{*m+1} \leftrightarrow y^m \ll y^{m+1}$ for $m = 1, 2, \ldots, a-1$,
  - $x_i^{*k} \le x_i^{*k+1} \leftrightarrow x_i^{*k} \ll x_i^{*k+1}$ for $k = 1, 2, \ldots a_i - 1$, where $\ll$ means "less preferred or indifferent to".

The size of the LP can be associated with reducing the monotonicity restrictions arising from the reduced computational effort needed to search for the optimum solution. This is followed by the formation of a series of transformation variables. These variables emphasize the successive steps of the value functions Y^* and $X_i{}^*$:

- $z_m = y^{*m+1} - y^{*m}$ for $m = 1, 2, \ldots, a-1$
- $w_{ik} = b_i x_i^{*k} + 1 - b_i x_i^{*k}$ for $k = 1, 2, \ldots, a-1$ and $i = 1, 2, \ldots, n$

The linearity of the model is accomplished by using these variables.

It is possible to write the variables included in the MUSA method by using the transformation variables as follows:

$$y^{*m} = \sum_{t=1}^{m-1} Z_t \quad \text{for } m = 2, 3, \ldots, a$$

$$b_i x_i^{*k} = \sum_{t=1}^{k-1} w_{it} \text{ for } k = 2, 3, \ldots, a_i \text{ and } i = 1, 2, \ldots, n.$$

After the introduction of the z_m and w_{ik} variables, the ordinal regression equation becomes as follows:

$$\sum_{m=1}^{t_j-1} z_m = \sum_{i=1}^{n} \sum_{k=1}^{t_{ji}-1} w_{ik} - \sigma^+ + \sigma^- \forall j$$

The final LP formulation of the method may be described as follows:

$$[\min] \, F = \sum_{j=1}^{M} \sigma_j{}^+ + \sigma_j^-$$

Subject to

$$\sum_{i=1}^{n} \sum_{k=1}^{t_{ij}-1} w_{ik} - \sum_{m=1}^{t_j-1} z_m - \sigma_j^+ + \sigma_j^- = 0, \forall j$$

$$\sum_{m=1}^{a-1} z_m = 100$$

$$\sum_{i=1}^{n} \sum_{k=1}^{a_i-1} w_{ik} = 100$$

$$z_m \geq 0, w_{ik} \geq 0, \sigma_j + \geq 0, \sigma_j - \geq 0 \forall i, j, k, m$$

where M is the number of students.

The calculation of the variables of the initial model is centered on the optimal solution of the previous LP, since:

$$b_i = \frac{1}{100} \sum_{t=1}^{a_i-1} w_{it} \text{for } i = 1, 2, \ldots, n$$

$$y^{*m} = \sum_{t=1}^{m-1} z_t \text{ for } m = 2, 3, \ldots, a$$

$$x_i^{*k} = 100 \frac{\sum_{t=1}^{k-1} w_{it}}{\sum_{t=1}^{a_i-1} w_{it}} \text{ for } i = 1, 2, \ldots n \text{ and } k = 2, 3, \ldots a_i$$

The eventual outcome is determined utilizing the average of the near optimal solutions of linear programing, which increment the weights of the n satisfaction criteria. A critical arrangement concerns the criteria weights bi, which describe the relative significance of the assessed satisfaction criteria (value trade-offs among the criteria). Several normalized indicators are recommended for the MUSA method that may uphold the top to bottom examination of the satisfaction analysis and involve different types (Grigoroudis & Siskos, 2002, 2010). The average indicators named; satisfaction indicators are ranged between [0, 1], which present the degree of customer global or criteria satisfaction. These indicators can be distinguished as the essential average performance indicators (globally or per criteria) for the company. The normalized indicators named; demanding indicators are ranged between [−1, 1] and they are determined by the arrangement of estimated added value curves. Moreover, these indicators represent consumers' demanding level (globally and per criteria) and they are recognized as an index for the degree endeavors that a company intends to enhance. The normalized average improvement indicators are ranged between [0, 1] and these indicators present the improvement margins on a particular criterion. The significance of the satisfaction measurements characterizes the effect of the amelioration endeavors and their commitment to dissatisfaction also.

Moreover, the outcomes can be optimized utilizing two types of diagrams; the action and improvement diagrams. These diagrams are created dependent on the previously mentioned results (Grigoroudis & Siskos, 2002, 2010). The first type of diagram is created combining criteria weights with satisfaction indices (Fig. 13.2). These diagrams are similar to SWOT analysis and they can outline the strong and weak dimensions of the company, in order to assist executives to distinguish which satisfaction dimensions should be enhanced (Grigoroudis & Siskos, 2002, 2010).

Action diagrams are separated into four quadrants and the satisfaction dimensions are presented into two actions named performance and importance. The term "Importance" refers to weight and "Performance" is the average satisfaction index. In other words, it is similar to the mean value of the initial function of LP. The improvement actions for every satisfaction dimension could be applied by the quadrant in which the dimension is represented. The characteristics of the status quo quadrant are low performance and low importance. In this way, no action is needed in light of the fact that consumers do not examine that these satisfaction dimensions are important. The characteristics of the leverage opportunity quadrant are high performance and high importance. This quadrant involves dimensions that can be described as competitive advantage. In a few cases, these dimensions explain the reasons why students have attended the course. In regards to transfer resources, quadrant characteristics are high performance and low importance. These assets might be better utilized somewhere else. For instance course's assets can be utilized for the purpose to enhance the satisfaction dimensions concerning the action opportunity quadrant. Ultimately, the characteristics of the action opportunity quadrant are low performance and high importance. More consideration should be paid to these criteria and in this manner improvement actions should be centered around these to improve the global student's satisfaction level.

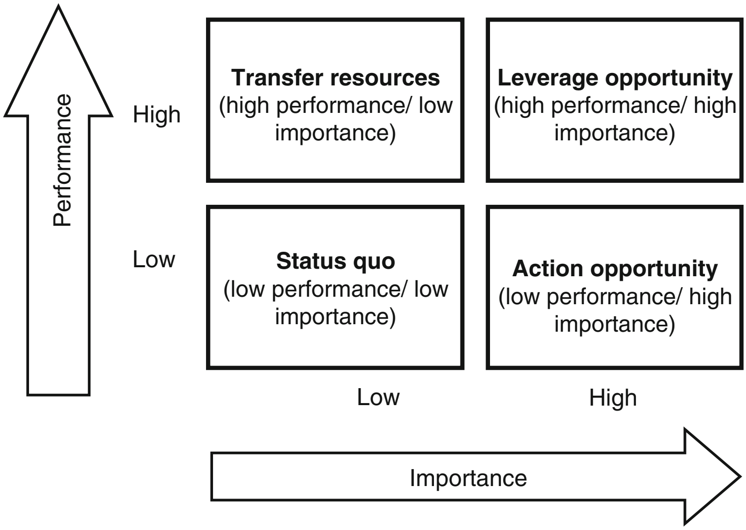

Fig. 13.2 Action diagram. (Adapted from: Grigoroudis and Siskos (2002))

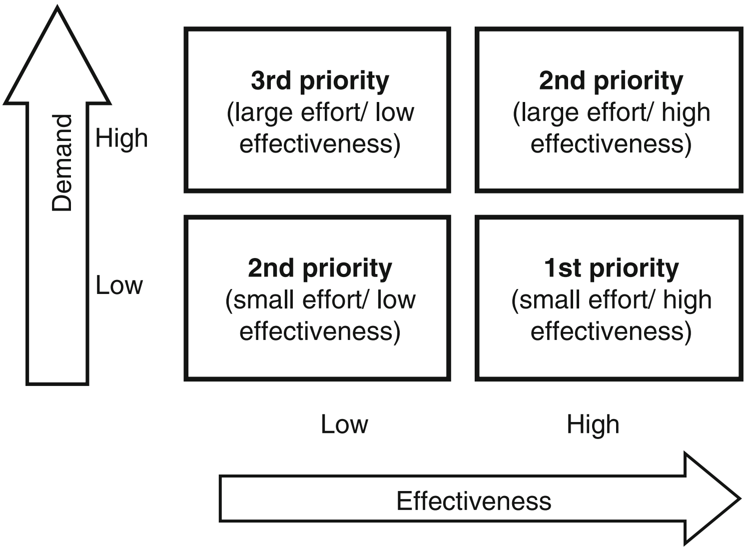

Fig. 13.3 Improvement diagram. (Adapted from: Grigoroudis and Siskos (2002))

Improvement diagrams are created combining improvement with demanding indices (Fig. 13.3). Rather than the action diagram that can just represent which satisfaction dimensions should be enhanced, these diagrams can assess improvement priorities and anticipate the yield or the degree of improvement endeavors.

Improvement diagrams can be characterized as dynamic since they can introduce just the existing circumstance of students' behavior. These diagrams are separated into four quadrants and the satisfaction dimensions are illustrated into two actions as per demanding and effectiveness. The improvement priorities for every satisfaction dimension could be assessed by the quadrant in which the dimension is outlined. First priority territory suggests unmediated improvement actions because these satisfaction dimensions are effective and consumers are not demanding. Then, second priority territory involves satisfaction dimensions that have either a low demanding indicator or a high improvement indicator. Last of all, third priority area incorporates satisfaction dimensions that have little enhancement margin and need improvement actions (Grigoroudis & Siskos, 2002, 2010).

In this research, Multi-criteria User Satisfaction Analysis was used to measure the satisfaction of students as well as to provide simultaneously the weak and strong satisfaction points (Ipsilandis et al., 2008). Among many other Operational Research methods, for example, goal programming, multisteps linear programming, integer programming, or dynamic programming, this method was chosen because it will display the weights and satisfaction indices for each criterion. Besides, the goal for this methodology is that the action and the improvement diagrams that are created can be utilized by instructors to know about the weak and the strong points of satisfaction. Moreover, the improvement diagrams give them a clearer perspective on the activities that must be improved (Grigoroudis & Siskos, 2002, 2010).

13.4 Results

13.4.1 Criteria Weights and their Variability

Criteria weights, b_i, present the relative importance given to each satisfaction dimension (criterion) by the participants. A criterion is considered important if $b_i > 1/n$, where b_i is the weight of the criterion and n is the number of criteria used in this study. In this case, $n = 6$ so the cutoff point is $1/6 = 0.16666$. Taking this into consideration, we can conclude that four criteria are viewed important: good teaching, generic skills, evaluation, and workload. Criteria weights variability can provide us with useful information regarding the stability analysis of the results, give us a confidence interval for the estimated weights and also identify possible competitiveness in the criteria set (Grigoroudis & Siskos, 2010). Table 13.1 presents criteria weights and their variability.

Table 13.1 Criteria weights and their variability

Criterion	Weight	Relative weight	Max	Min
Good teaching	0.17333	0.132	60	8
Clear targets	0.12839	−0.756	37.033	8
Independence	0.15629	−0.205	53.55	8
Generic skills	0.17742	0.212	60	8
Evaluation	0.19532	0.566	60	8
Workload	0.16925	0.051	57.55	0

Table 13.2 Criteria satisfaction indices and demanding indices

Criterion	Satisfaction index	Demanding index
Global	66.996%	−35.196
Good teaching	68.749%	−42.293
Clear targets	31.863%	37.689
Independence	69.637%	−48.814
Generic skills	62.123%	−28.135
Evaluation	77.058%	−58.505
Workload	73.711%	−52.733

13.4.2 Satisfaction and Demanding Indices

Satisfaction indices are the mean value of the global or marginal value functions, normalized in the interval [0, 100%]. They can be used in satisfaction analysis and benchmarking.

In this study, participating students are 66.99% satisfied from the course, while evaluation criterion has the highest satisfaction index (77.06%) and contrariwise, clear targets criterion has the lowest (31.86%). Demanding indices are the average deviation of the estimated value curves from a linear function. They can take various values for various levels of the ordinal satisfaction scale. Overall, students are not demanding and similarly, they are not demanding in five out of six criteria (good teaching, independence, generic skills, evaluation, workload) as suggested by the negative value of their respective index. On the contrary, only clear targets criterion's index is positive and students are demanding, regarding this criterion. Satisfaction and demanding indices are presented in Table 13.2.

13.4.3 Global Satisfaction Function

Global satisfaction function presents the real value given by the participants to each level of the function, in the interval [0, 100]. Both global Y^*, and partial satisfaction functions, X_i^* are mentioned as additive and marginal value or utility functions. These functions are monotonic, nondecreasing, and discrete, while their form indicates whether the participants are demanding or not. The global satisfaction function represents the participants' preference value system (Grigoroudis & Siskos, 2002).

The global satisfaction function is presented in Fig. 13.4. It is a concave value function which means that the users are not demanding. Global Satisfaction Values are presented in Table 13.3.

As per MUSA methodology, the form of the global satisfaction function indicates the participants' degree of demanding. The concave form of the specific function, suggests that the participants are not demanding. Participants' degree of demanding

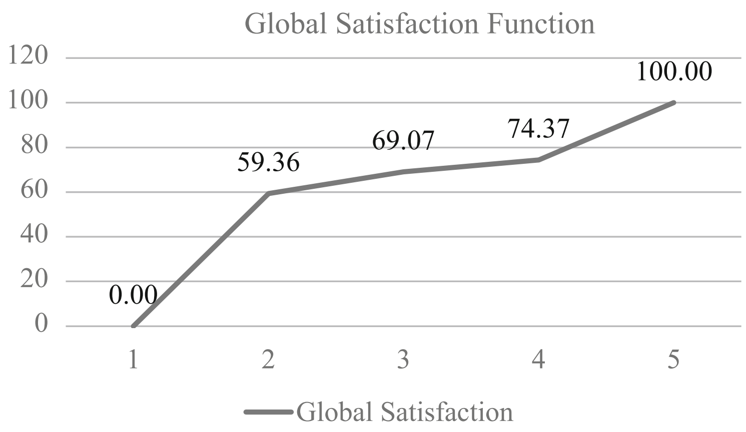

Fig. 13.4 Global Satisfaction Function

Table 13.3 Global satisfaction function values

Scale value	Additive value
1	0
2	59.359
3	69.067
4	74.367
5	100

is also indicated by the negative value of the global demanding index (−35.293) from Table 13.2.

13.4.4 *Partial Satisfaction Functions*

Similarly, the form of the partial satisfaction functions also indicates the participants' demanding degree. As indicated by the demanding indices in Table 13.4, participants are demanding only regarding the clear targets of the course and the convex form of the corresponding function in Fig. 13.5 confirms this inference. Table 13.4 presents the scale and additive value for each criterion and Figs. 13.7, 13.8, 13.9, 13.10, 13.11, and 13.12 in Appendix 2 represent the partial satisfaction function of each criterion.

13.4.5 *Relative Action Diagram*

Action diagrams are developed by combining criteria weights, in the horizontal axis (importance) and satisfaction indices in the vertical axis (performance). These

Table 13.4 Partial satisfaction function by criteria—additive values

Additive value	Teaching quality	Clarity of goals	Appropriate workload	Appropriate assessment methods	Generic skills	Independence in learning
1	0	0	0	0	0	0
2	55.748	15.578	61.61	52.795	69.013	64.549
3	73.077	31.155	74.407	64.068	79.253	76.366
4	84.615	46.733	87.203	75.341	89.492	88.183
5	100	100	100	100	100	100

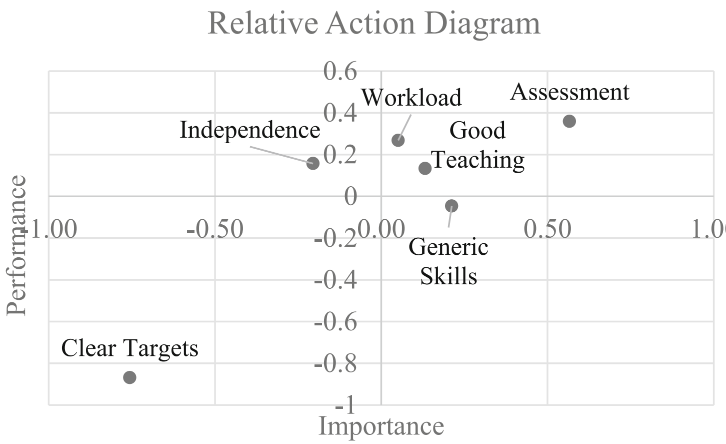

Fig. 13.5 Relative action diagram

values can be normalized in the [−1, 1] interval and develop the relative action diagram. The normalization formula for calculating relative criteria weights is $b\prime_i = \frac{b_i - \overline{b}}{\sqrt{\sum_i (b_i - \overline{b})^2}}$, where b_i is the weight of each criterion and $\overline{b}$is the mean value of the weights. The corresponding formula for calculating relative satisfaction indices is $S\prime_i = \frac{S_i - \overline{S}}{\sqrt{\sum_i (S_i - \overline{S})^2}}$, where S_i is the satisfaction index of each criterion and $\overline{S}$ is the mean value of satisfaction indices. The relative action diagram, presented in Fig. 13.5, is divided into quadrants. The upper right quadrant (high performance and high importance), the quadrant of leverage opportunity, contains three criteria: evaluation, good teaching, and workload. These criteria can be advertised as competitive advantage against other courses.

The upper left quadrant (the transfer resources quadrant with high performance and low importance) contains the criterion of independence, which means that the course teachers can transfer resources from this criterion to the generic skills criterion in the lower right quadrant which is the action opportunity quadrant, containing criteria that are considered important by the participants but these criteria also have low performance and need to be improved. The lower left quadrant, the status quo quadrant, contains criteria that are not deemed as significant by the

Table 13.5 Criteria relative weights and relative satisfaction indices

Criterion	Relative weight (importance)	Relative satisfaction index (performance)
Good teaching	0.132	0.133
Clear targets	−0.756	−0.869
Independence	−0.205	0.157
Generic skills	0.212	−0.047
Evaluation	0.566	0.359
Workload	0.051	0.268

participants and their performance is also low. No further actions are required for the clear targets criterion which is the only one in this quadrant. Table 13.5 presents criteria relative weights and relative satisfaction indices and Fig. 13.5 presents the relative action diagram.

It becomes evident by the relative action diagram that the students enrolled in the course are satisfied and not demanding. Workload, assessment, good teaching, and generic skills are considered significant criteria with only two out of six specific goals and independence being unimportant for the students. Assessment, workload, and adequate teaching, all be used as a competitive advantage to draw more students to the course. Curriculum designers, on the other hand, must bear in mind that completing this course is an invaluable experience for students to improve their generic skills. The average satisfaction index for this parameter is low, so attempts to progress in this direction should be made as a result. While students are granted a great deal of independence, it is not respected. Resources can be shifted to other criteria. As a "status quo" feature, the statement of the goals of the teachers and the objectives of the courses are considered.

13.4.6 Relative Improvement Diagram

Figure 13.6 presents the relative improvement diagram. The values on the horizontal axis are the improvement indices of the criteria. The improvement index of a criterion is calculated as follows: $I_i = b_i(1 - S_i)$, where b_i is the weight and S_i the satisfaction index of each criterion and are normalized in the [−1, 1] interval using the following formula $I\prime_i = \frac{I_i - \overline{I}}{\sqrt{\sum_i (I_i - \overline{I})^2}}$, where I_i is the improvement index of each criterion and $\overline{I}$ is the mean value of improvement indices. The improvement index is a measure of the improvement effort required for each criterion. The values on the vertical axis are the demanding indices of the criteria. Combining these two values, we create the relative improvement diagram. Table 13.6 summarizes relative improvement indices and relative demanding indices.

The quadrants of the diagram represent the priorities that should be given to the effects for improvement for each criterion. The lower right quadrant includes criteria that should be of top priority for improvement, as the extent of the efforts required

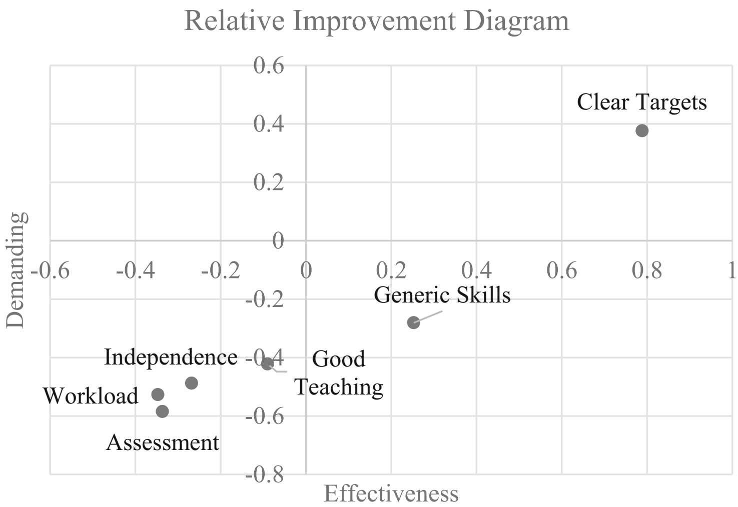

Fig. 13.6 Relative improvement diagram

Table 13.6 Relative improvement indices and relative demanding indices

Criterion	Relative improvement index (effectiveness)	Relative demanding index (demanding)
Good teaching	−0.08994	−0.422
Clear targets	0.78883	0.376
Independence	−0.26823	−0.488
Generic skills	0.252957	−0.281
Assessment	−0.33647	−0.585
Workload	−0.34715	−0.527

is low but their effectiveness is high. As expected, generic skills criterion is located in this quadrant; the importance of this criterion is high while its performance is low. All others criteria should come after in priority order. Upper right quadrant represents large efforts with high effectiveness. Only one criterion is here. Clear targets have the lowest performance of all criteria but they are also not important for the participants of the study. This is why it should be of second priority. Lower left quadrant also contains second priority criteria. Although the improvement efforts that are needed are not being significantly made for now their effectiveness is also low. All four remaining criteria, namely good teaching, independence, evaluation, and workload are in this quadrant. Finally, upper left quadrant contains criteria of third priority, that require high improvement efforts but are of low effectiveness. There are no criteria in this quadrant.

13.5 Comparison Between Secondary and Tertiary Education Students' Course Evaluation

The CEQ was originally developed for course evaluation in higher education. As a consequence, the great majority of previous studies concern higher education, either as course evaluations or instrument validation studies (Fryer et al., 2012; Law & Meyer, 2011a; Rahman et al., 2012; Ramsden, 1991; Stergiou & Airey, 2012; Ullah et al., 2011). The use of the CEQ has been validated as an instrument for students' course evaluation in secondary education only recently (Chakrabarty et al., 2016). To the best of our experience the methods of multi-criteria decision-making, and specifically MUSA is applied for the first time in combination with the CEQ, either in higher or in secondary education. All previous studies use traditional methods of statistical analysis, for example, factor analysis or regression. The results of the current study are aligned to those of previous studies both in higher and in secondary education. However, the implementation of MUSA method offers a number of benefits in comparison to traditional approaches, explained further in the comparison below.

Chakrabarty et al. (2016) are the only researchers that used the CEQ in secondary education and the findings of their study were very similar to these of the current study. The authors administered a Bengali translated version of the CEQ to 552 high school students, studying Science, in West Bengal, India. The purpose was to validate the instrument for evaluation purposes in secondary education. The Exploratory Factor Analysis highlighted only three of the six factors of the original scale, namely effective teaching, generic skills, and sufficient workload, ordered according to the proportion of variability explained by each factor. Additionally, a fourth factor, student support, was produced. Law and Meyer (2011a), on the other hand, came up with similar results in an attempt to validate the CEQ in the Chinese context using a sample of six higher education institutions. Again, only three factors were extracted from the factor analysis, namely effective teaching, sufficient workload, and generic skills development, ordered by the produced amount of variability. However, the analysis, in both cases, failed to identify the rest of the CEQ constructs.

These results support Gibson's findings (2010) who claimed that the core attributes of a course, including quality of teaching, curriculum, and skills are the most important ones for the participating students. Waugh (1998), on the other hand, concluded that teaching and skills should be interpreted separately as these attributes have the greatest fit with the concept of students' satisfaction.

Other applications of the CEQ in higher education, report significant correlations among effective teaching, consistency of goals, emphasis on independence and appropriate assessment, and students' satisfaction. Ramsden (1991), working on a sample of 13 higher education institutions in Australia, concluded that good teaching and appropriate assessment are linked with students' satisfaction and deep learning approach. This finding was confirmed in a later research by Rahman et al. (2012), who used the CEQ to evaluate a higher education engineering course learning environment in Malaysia. According to Rahman et al. (2012), surface learning approach is mostly related to inappropriate workload. Since deep learning approach is associated to better quality of learning, the authors suggested that increasing the efforts for effective teaching and appropriate assessment, and at the same time reducing workload, can benefit the students' quality of learning. However, Ramsden (1991) concluded that these measures should make meaningful comparisons on teaching performance only within similar fields or disciplines. Fryer et al. (2012) used the CEQ to examine the learning approaches of Economics and Commerce students, in Japan. The authors identified four factors in their Factor Analysis, namely effective teaching, generic skills, appropriate assessment, and sufficient workload. Good teaching and generic skills had strong positive correlations to deep learning approaches.

Ullah et al. (2011) studied learning approaches in conjunction to students' satisfaction with learning environment, in multiple departments of two universities in Pakistan. Only four of the six factors were identified by the Exploratory Factor Analysis. The first factor was instructional practices (incl. good teaching and increased focus on independence items), the second was appropriate workload, the third was generic skills (incl. clear goals items), and the fourth was appropriate assessment. The first three of these factors exhibited significant positive correlations to overall students' satisfaction, whereas appropriate assessment remained totally uncorrelated.

In the Greek context, Stergiou and Airey (2012) worked on a sample of higher education students in tourism programs with similar results. However, the level of importance is differentiated, as Skills Development attribute is considered the most important one among good teaching and appropriate assessment, while secondary education students consider the Appropriate Assessment attribute as the most important followed by skills and good teaching. As Stergiou and Airey (2012) claimed, the nature of the course, i.e., vocational or academic, is undoubtedly associated with the importance of one criterion over another. In our opinion, the level of studies may also be influential on the relative importance of each criterion.

All in all, regardless of the educational level, only small differences are observed in the results of all previous studies. The same attributes affect students' satisfaction from the learning environment, in most cases. Four factors are dominant in the results of all studies, both in higher and secondary education; good teaching, appropriate assessment, sufficient workload, and generic skills. However, the importance of each attribute is differentiated throughout the studies, which could be explained due to sample differences. Additionally, those studies utilizing traditional statistical approaches (e.g., factor analysis and regression analysis), either failed to identify some of the six factors of the original CEQ, or had insignificant effects, and therefore it was not possible to infer the relative importance of each one of them. A comparison between previous researches in higher and secondary education is summarized in Table 13.7.

Table 13.7 Comparison between previous researches in higher and secondary education

Author (year)	Education level	Methods of analysis	Type of questionnaire used	Country of application	Type of course	GT	AA	AW	GS	CG	IL
This study[a]	Secondary education	MCDM	36 item CEQ	Greece	ICT course	3[b]	1[b]	4[b]	2[b]	6[b]	5[b]
Chakrabarty et al. (2016)	Secondary Education	Exploratory Factor Analysis	36 item CEQ	India	Science course	1[b]		3[b]	2[b]		
Stergiou and Airey (2012)	Higher Education	Structural Equation Models/ Confirmatory Factor Analysis	31 item CEQ + academic environment scale	Greece	Tourism	2[b]	3[b]	4[b]	1[b]	5[b]	
Fryer et al. (2012)	Higher Education	Exploratory and Confirmatory Factor Analysis	36 item CEQ	Japan	Economics and Management	2[b]	b	b	1[b]		
Rahman et al. (2012)	Higher Education	Multiple Regression	36 item CEQ and WIHIC	Malaysia	Technical Institute	2[b]	1[b]			3[b]	
Law and Meyer (2011a, 2011b)	Higher Education	Exploratory Factor Analysis	36 item CEQ	Hong Kong	Various departments	b		b	b		
Ullah et al. (2011)	Higher Education	Exploratory Factor Analysis	36 item CEQ	Pakistan	Business and Management, Technology, Social Sciences	1[b]	b	3[b]	2[b]		
Ramsden (1991)	Higher Education	Exploratory Factor Analysis	30 item CEQ	Australia	Various departments	1[b]	3[b]			2[b]	4[b]

GS = generic skills, GT = good teaching, AA = appropriate assessment, AW = appropriate workload, IL = independence in learning, CQ = clear goals
[a]High importance attributes according to the Relative Action Diagram Fig. 13.5
[b]Identified criteria with a relative ranking based on statistical measures where available

13.6 Conclusion

Course evaluation is considered an important process for both tertiary and secondary education. In recent years, many researchers have paid attention to the use of Course Experience Questionnaire. The CEQ evaluates students' satisfaction, based on six separate criteria that illustrate the relationships among them and the course performance. It is primarily used in higher education while only applications are met in secondary education. However, the traditional statistical analysis of the CEQ data cannot provide satisfactory explanations for constructs relationships, and it is challenging for researchers to make fast and reliable decisions of each criterion's success in reference to the requirements of students.

The MUSA method used in this study has the benefits of recognizing both the strong and the weak points of students' satisfaction, with valuable implications for all stakeholders. The results of the study offer educators a tool to recognize the essential factors that adversely impact on the satisfaction of students and ultimately impact the achievement of students. More specifically, the students of the course under evaluation, proved to be non-demanding, according to the global satisfaction function. A potential reason for this phenomenon may be that students do not consider that the ICT course is fundamental in comparison to other courses in the curriculum. Possible causes behind this result could be that the course was taught only for 2 h per week. This inference is corroborated also by the fact that all partial satisfaction functions show that students are demanding only when it comes to the clarity of goals. Unfortunately, they are not demanding in good teaching, sufficient workload and assessment, development of skills, and independence in learning. These results are justified by the reduced time per week devoted to this course, since the time constraints made it difficult for students to be seriously concerned about their performance in comparison to other courses (e.g., math and chemistry) that dominate the curriculum.

Nevertheless, according to the Relative Action Diagram, educators should continue their efforts towards good teaching, balanced workload, and flexible evaluation procedures which are the strong assets of the course. They should also take care of the development of generic skills of students attending this course, which is important for them, and can offer a great amount of satisfaction, according to the Relative Action Diagram. The Clarity of targets seems to be of great effectiveness and demand, therefore, educators have to spend adequate time explaining what is expected from students, what will be achieved, and how these achievements are related to professional and technical skills. All other criteria are of lower demand, however, regarding their effectiveness, generic skills development appears to require some improvement, as well.

The contribution of this chapter is based on the implementation of a multi-criteria method for course assessment. The MUSA method has never been used for educational course evaluation before. This method helps practitioners to understand the role each criterion performs in the course's success, but also the importance to the students of each criterion. The produced diagrams can support educators to easily identify the critical factors that affect the performance of a course, and to take students' evaluation into consideration, in order to design their interventions.

Moreover, integrating CEQ with multi-criteria analysis has many advantages for course evaluation. First, all criteria are considered concurrently, and a significance weight is determined for each criterion. Second, MUSA produces a value function based on student's overall and partial satisfaction judgments. The value function will explicitly provide data about demand, distinguishing neutral, demanding and non-demanding students. Third, the action diagram which helps executives in the decision-making process is presented by MUSA. The action diagram is actually a map of segregated segments focused on the importance of each to the assessed course. The findings are similar to SWOT analysis since the criteria are split into four groups, namely status quo, leverage opportunity, transfer resources, and action opportunity. This classification of these criteria can provide useful information for decision makers. They could be aware of those criteria that are the competitive advantage, the criteria of high importance that need an urgent intervention and the criteria that are considered as valuable resources that do not have a valuable impact on the overall performance of the course.

In conclusion, MUSA provides curriculum designers with a tool in order to evaluate and improve their courses and supports them to better design their courses in the future. Last but not least, the method can also increase students' interest, as it offers good possibilities to start a participatory model of decision making, through fertile discussion between students and teaching staff. The relative action and improvement diagrams are important tools for the support of rational decision-making in education. The analysis of students' evaluations of educational courses or programs can help decision makers understand which dimensions of satisfaction need to be changed in order to schedule appropriate interventions to increase course performance.

Future work could examine if there is a difference in the level of students' satisfaction taking demographic factors such as the sex and specialty of studies into account. Regarding the evaluations of ICT courses, beyond general skills development, the development of students' ICT related skills could be additionally analyzed, to evaluate the significance of these skills, in this setting, in comparison to the other dimensions of the tool.

Appendix 1: The Original and Adapted CEQ Items

	Original CEQ	Adapted Questionnaire item
Teaching quality		
1	Teachers here make a real effort to understand the difficulties we are facing during learning	How satisfied are you with the effort teachers here make to understand the difficulties you are facing during learning?
2	Teachers of this course put a lot of time into commenting on our work	How satisfied are you with the time devoted by teachers of this course to comment on your work?
3	The teachers of this course motivate us to do the best work	How satisfied are you with the motivation given by the teachers of this course to do your best work?
4	Teachers here normally give helpful feedback on our performance	How satisfied are you with the usefulness of the feedback provided by teachers on your performance?
5	Teachers of this course work hard to make subjects interesting	How pleased are you with the effort of the teachers of this course to make subjects interesting?
6	Teachers here are extremely good at explaining content to us	How satisfied are you with the teachers' explanations about the content?
7	This course really tries to get the best out of all the students	How satisfied are you with efforts during this course to get the best out of all the students?
8	Teachers of this course are really interested in students' opinions	How satisfactory is the real interest of teachers in students' opinions?
Clarity of goals		
1	Teachers here make it clear right from the start what they expect from us	How satisfied are you with teachers making it clear right from the start what they expect from you?
2	It is always easy here to know the standard of work expected	How satisfied are you with the ease to always know the standard of work expected?
3	The aims and objectives of this course are not made very clear	How satisfied are you with the clarity of the aims and objectives of this course?
4	It is often hard to know what is expected of me in this course	How satisfied are you with the chance to know what is expected of you in this course?
5	I have a clear idea of where I am going and what is expected of me	How satisfied are you with the clarity of understanding where you are going and what is expected of you in this course?

	Original CEQ	Adapted Questionnaire item
Appropriate workload		
1	The workload of this course is too heavy	How satisfied are you with the amount of work required from this course?
2	It seems to me that the syllabus of this course is vast	How satisfied are you with the size of the syllabus of this course?
3	The volume of work to get through in this course means I cannot comprehend it all thoroughly	How satisfied are you with the amount of effort needed to get through in this course?
4	In this course, we are given enough time to understand the things that we have to learn	How satisfied are you with the time available to understand all the things you have to learn in this course?
5	In this course, it is really easy to know the standard of work expected	How satisfied are you with the ease to always know the standard of work expected?
Appropriate assessment methods		
1	Teachers of this course frequently give the impression that they have nothing to learn from us	How satisfied are you with the frequency the teachers of this course give the impression that they have something to learn from you?
2	There is a lot of pressure on me as a student here	How satisfied are you with the pressure on you as a student of this course?
3	Usually, feedback on our work is provided only in marks	How satisfied are you with the ways of getting feedback on your performance other than marks?
4	To do well in this course we all really need a good memory	How satisfied are you with the requirements to memorize things during this course?
5	Teachers of this course are more interested in testing what I have memorized than what I have understood	How satisfied are you with teachers examining what you have really understood?
6	Most of the teachers here ask questions on facts	How satisfied are you with the questions asked by teachers in this course?
Generic skills		
1	This course has improved my written communication skills	How satisfactory is the improvement of your written communication skills during this course?
2	This course has helped me to develop my problem-solving skills	How satisfactory is the development of your problem-solving skills during this course?
3	This course has helped me in developing the ability to plan my own work	How satisfied are you with the development of your ability to plan your own work during this course?
4	As a result of pursuing this course, I feel more confident about tackling unfamiliar problems	How satisfied are you with the development of your confidence to cope with nontrivial problems?
5	This course has sharpened my analytic skills	How satisfied are you with the degree this course sharpened your analytic skills?
6	This course has helped me in developing my ability to work as a team member	How satisfied are you with the development of your ability to work as a team member in this course?

	Original CEQ	Adapted Questionnaire item
Independence in learning		
1	We often discuss with our teachers here on our ways of learning	How satisfied are you discussing with your teachers here on your ways of learning?
2	Students of this course are given a great deal of opportunity in selecting for themselves their ways of learning	How satisfied are you with the opportunities given in this course in selecting your ways of learning?
3	There is very little choice in this course in the ways I am assessed	How satisfied are you with the choices given in this course in the ways you are assessed?
4	There are few opportunities to choose the particular areas I want to study	How satisfied are you with the choice you have on a particular area you want to study?
5	Students of this course are given a lot of choice in the work that they have to do	How satisfied are you with the different choices you are offered about the work you have to do in this course?
6	This course has developed my academic interest as far as possible	How satisfied are you with the development of your academic interests in this course?

Appendix 2: Partial Satisfaction Functions

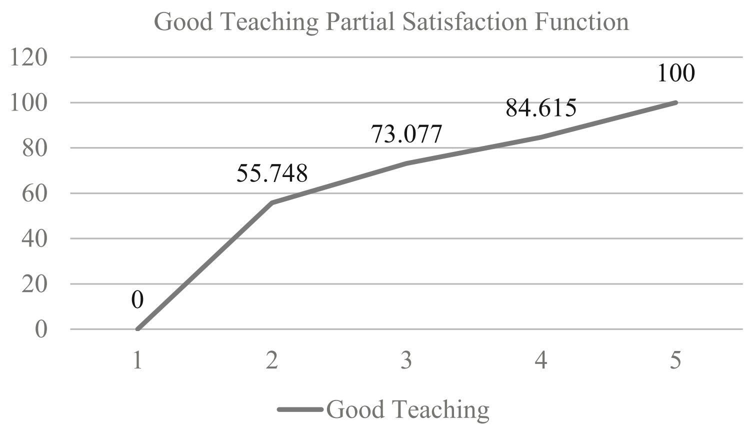

Fig. B.1 Good teaching partial satisfaction function

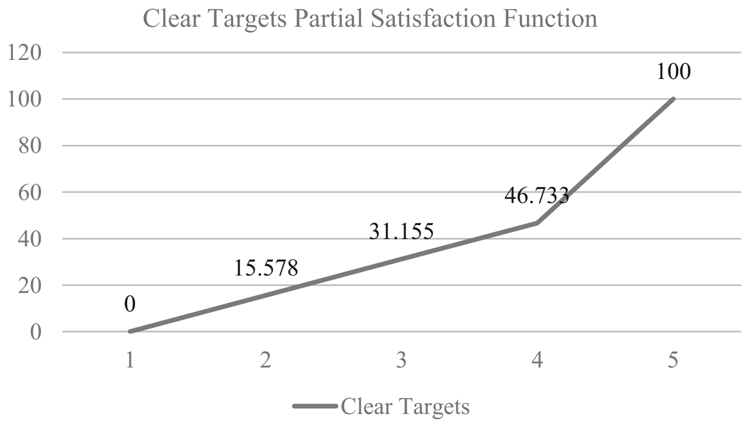

Fig. B.2 Clear targets partial satisfaction function

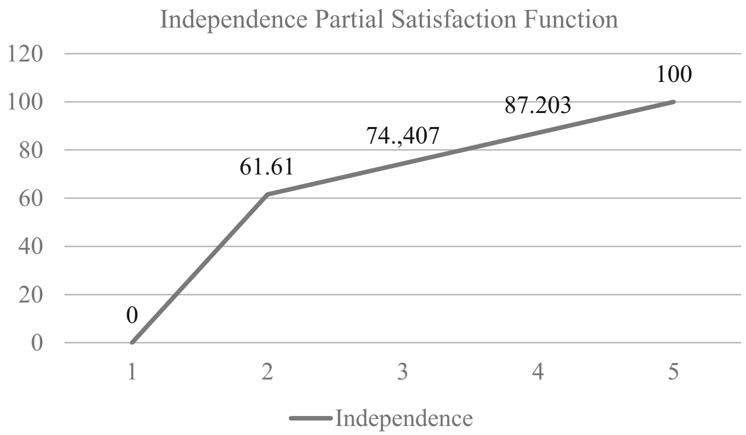

Fig. B.3 Independence partial satisfaction function

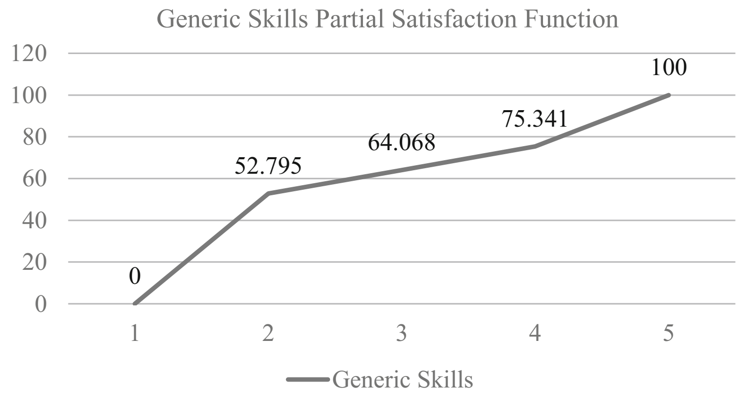

Fig. B.4 Generic skills partial satisfaction function

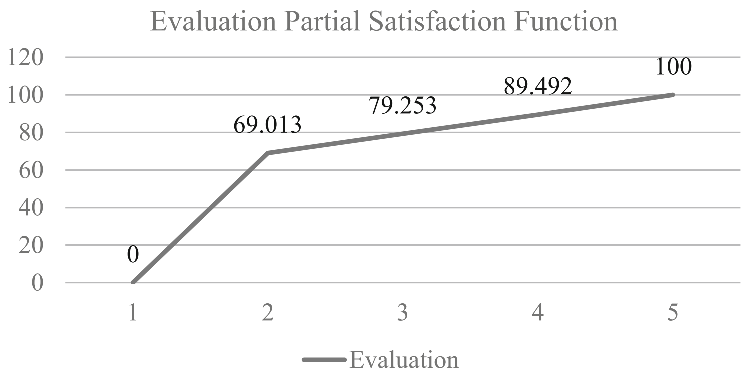

Fig. B.5 Evaluation partial satisfaction function

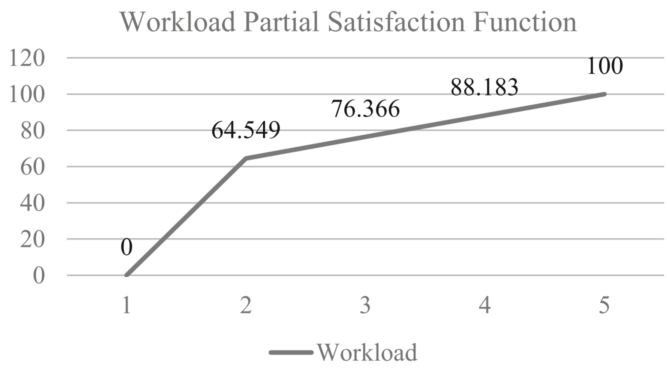

Fig. B.6 Workload partial satisfaction function

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Chapter 14
The Application of a Balanced Scorecard in Higher Education Institutions: A Case Study of Wuls

Michał Pietrzak

Abstract The purpose of this chapter is to share the experience of a Balanced Scorecard (BSC) development and application by a public university. This case study is used to describe the process of developing a strategy and translating it into a customized Balanced Scorecard. The project presented in this chapter did not lead to amazing success, but it did not completely fail. This project was adapted to the specific conditions of a particular time and place and spanned 10 years, even though changes in the model were made over time due to new laws at the national level. Some of the lessons learned are discussed in the last section of this chapter. The administrators of Higher Education Institutions can directly use or adapt the BSC framework presented in this chapter. Moreover, they can find some useful tips and tricks regarding the basic steps in the process of strategy and Balanced Scorecard development. Moreover, interested parties could deliberate upon some problems and challenges pinpointed in this case study and consider such issues in advance. This study will be helpful in designing customized strategic management systems adapted to the specific circumstances of a time and place, instead of simply imitating and replicating solutions developed for business firms.

Keywords Balanced Scorecard · BSC · Strategic management · HEIs · Academic governance

14.1 Introduction

The Balanced Scorecard (BSC) was developed by Kaplan and Norton 29 years ago and was initially positioned as a performance measurement system (1992). Since that time, the conception has evolved. According to Kaplan and Norton (2004), managers appreciate the comprehensive performance measurement system.

M. Pietrzak (✉)
Institute of Economics and Finance, Warsaw University of Life Sciences, Warsaw, Poland
e-mail: michal_pietrzak@sggw.edu.pl

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However, they also desire to use this new system to solve the problems they face—how to execute a strategy. Thus, BSC today is perceived mainly as a methodology to support strategic management (Kaplan & Norton, 1996, 2001, 2004, 2006, 2008). The Balanced Scorecard has been adopted by many companies worldwide. According to the survey of Bain&Co. conducted among 1268 managers, BSC is among the TOP 25 most popular management tools, with a 29% of usage rate (Rigby & Bilodeau, 2018).

While typically applied in business, BSC has also gained popularity in public agencies and non-profits (Niven, 2008). This trend is particularly observable in the public sector, where the concept of New Public Management (NPM) has been spread widely in many OECD countries (Hood, 1991; O'Flynn, 2007). This concept relies on markets, rather than planning; performance measurements; monitoring and management systems; and empowered and entrepreneurial management instead of collegial decisions (Ferlie et al., 2008). Moreover, Higher Education Institutions (HEIs) have become the places of application for the NPM (Schimank, 2005; Tahar, 2013; Wilkesman & Schmid, 2012). Consequently, HEIs have started to implement modern managerial tools developed for business. Some of them have started to use BSC (Asan & Tanyas, 2007; Juhl & Christensen, 2008; McDevitt et al., 2008; Papenhausen & Einstein, 2006; Tapinos et al., 2005; Taylor & Baines, 2012; Umashankar & Dutta, 2007).

This chapter presents a case study of one such application using the example of a Polish university. The case study object is one of the 20 largest universities in Poland. A Polish example could be particularly interesting for countries experiencing political and socioeconomic transitions, as well as those that have witnessed the massification of higher education. Moreover, some traits of public universities are quite common worldwide, so a case study of Balanced Scorecard's application in a public university could shed light on some typical issues and obstacles that are widespread in such higher education institutions. The results of the BSC application can be considered ambiguous. The project did not lead to amazing success, but it did not fail completely. As time passed, our team ceased pursuing the perfect application of BSC for practical reasons. Our version of the BSC strategic model was adapted to the specific conditions of a particular time and place. However, the project survived for 10 years, even though changes in the model took place over time due to new laws at the national level related to higher education in Poland. Some of the lessons learned are discussed in the last section of this chapter.

This case study could be useful for administrators of HEIs, particularly publicly owned ones, who can use or adapt the BSC model presented here, as well as can find some tips and tricks regarding strategic management and the Balanced Scorecard's application. Interested readers could also consider some possible problems and obstacles in advance. This case study could also facilitate some thoughts about public policy regarding HE and about the development and cascading of a nationwide strategy. Therefore, this chapter will be interesting for politicians and decision makers in the HE sector. Lastly, this chapter seeks to invigorate critical discussion among academics, the ultimate executors of any strategy in HE.

14.2 A Short Presentation of the Warsaw University of Life Sciences

The origins of the Warsaw University of Life Sciences (WULS) date back to 1816. With its over 200-year tradition, this school is one of the oldest universities in Poland. Presently, the university consists of 13 faculties (Agriculture and Biology; Veterinary Medicine; Forestry; Horticulture and Biotechnology; Civil and Environmental Engineering; Wood Technology; Animal Breeding, Bioengineering, and Conservation; Economics; Food Technology; Human Nutrition; Production Engineering; Sociology and Education; and Applied Informatics and Mathematics). Due to the latest national reform of the HE system, a matrix structure was introduced. While the faculties are responsible for teaching, research activity is managed across 18 institutes. However, this is only a recent change, which had no impact at the time when the strategy and BSC were prepared (Report by professor Wiesław Bielawski, rector of the WULS, 2020).

There are about 18,000 students (including 590 foreign students, as well as PhD and postgraduate students) enrolled at WULS, who are taught by nearly 1200 academic staff. WULS' share in the whole sector is around 1.5%, and within the group of life sciences universities, its share is nearly 32%, as measured by the number of students. WULS cooperates with over 275 foreign universities from 50 countries all over the world. Since 1990, WULS has actively participated in European programs as a university from an associate, candidate, and—since 2004—EU member-state country. The university is a member of international organizations such as the Euroleague for Life Sciences (ELLS), the European Universities Association (EUA), the Interuniversity Consortium for Agricultural and Related Sciences (ICA), and many others. The 70-hectare campus of WULS, located in the southern part of Warsaw, has a historical part, featuring an eighteenth-century palace, and a contemporary part, where most of the faculties' buildings along with the 14 dormitories (4000 rooms), library, and sports center are located (Facts and Figures, 2020; Report by professor Wiesław Bielawski, rector of the WULS, 2020).

The faculties of WULS are differentiated not only by research area but also by other dimensions such as size (measured by the number of academic staff employed) and outputs, as measured by the number of students enrolled or the number of score points assigned to research publications (Table 14.1). For many years, the governments and bureaucrats responsible for HE have made attempts to determine a "proper measure" of research output, while still taking into account research quality. Recently, two special lists were published by the Ministry of Science and Higher Education. Based on the first list, score points were assigned to nearly 30 thousand journals worldwide. For having a paper published in any journal from that list, a researcher can receive from 20 to 200 points. The second list consists of editing houses: For a monograph published by an editing house from this list, 80 to 200 points are available (split up in the case of an edited book). Score points are an

Table 14.1 Differences between the faculties of WULS as of 2019

Faculty	Academic staff [persons]	Students [persons]	Score points [#]	Students per staff ratio [#]	Research vs. teaching orientation [#]
Veterinary Medicine	155	1227	13,157	8	11
Civil and Environmental Engineering	155	1844	10,154	12	6
Economics	145	2943	10,514	20	4
Agriculture and Biology	134	1113	15,598	8	14
Human Nutrition	112	1447	14,444	13	10
Food Technology	92	1158	8469	13	7
Forestry	78	1297	7431	17	6
Animal Breeding, Bioengineering, and Conservation	74	941	4081	13	4
Horticulture and Biotechnology	58	1093	3709	19	3
Production Engineering	57	834	5390	15	7
Wood Technology	49	577	3670	12	6
Applied Informatics and Mathematics	47	1054	3157	22	3
Sociology and Education	42	789	1973	19	3
Total/mean	1198	16,317	101,747	14	6
Total/mean in Poland	93,100	1,230,300	na	13	na

Source: Report by professor Wiesław Bielawski, rector of the WULS, 2020, pp. 13–14, 104, 242–243, and author's calculations (last two columns)

element of both the individual assessment of the staff and the evaluation of the HEI. In the second case, the portion of public funds can be adjusted accordingly. Nevertheless, the dominant stream of governmental money is still tied to teaching activity.

According to Warning (2004), universities make the trade-off between an emphasis on teaching or research activity. Following this, I calculated two indexes: the number of students per academic staff and the score points per academic staff. When we divided the second by the first, we derived an indicator called research vs. teaching orientation (the low value of this measure indicates relatively more focus on teaching, while a high value indicates a greater focus on research). One can find substantial differences in both these orientations across the faculties of WULS (Table 14.1 and Fig. 14.1). Some of these differences are evidently more oriented toward teaching, while others rely much more on research. Still, some of them exist in the middle without a clear orientation.

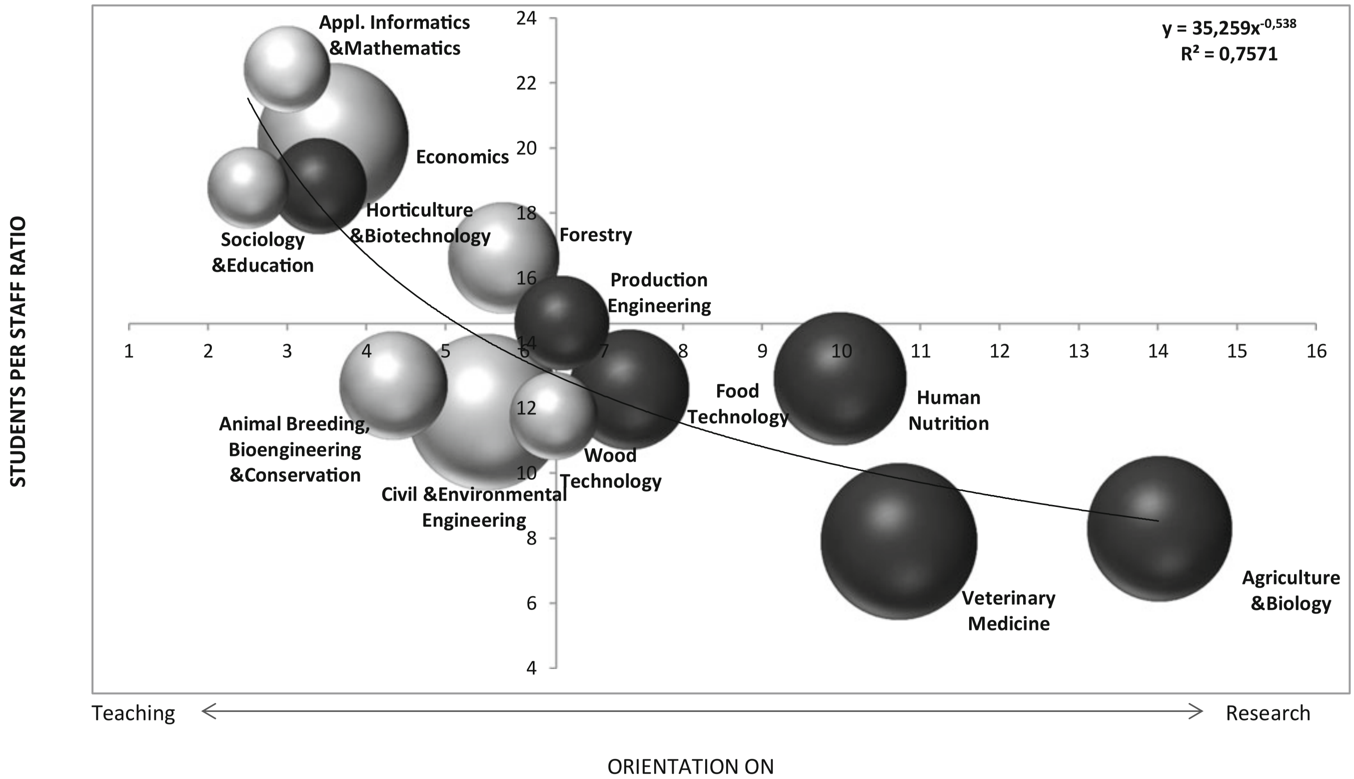

Fig. 14.1 Diversity of the faculties of WULS. (Notes: (1) The sizes of the bubbles depict the scale of the faculties as measured by academic staff; (2) Colours: dark grey denotes A or A+ category (the best); light grey denotes B category (medium); no one faculty belong to the C category (the worst). Categories are assigned by the government on the basis of an evaluation of scientific activities done over four years. Source: Based on data from Table 14.1 and the author's notes from strategic meetings)

14.3 Context of BSC's Introduction

To explain the context of BSC's implementation at WULS, this section provides a short overview of the situation of HE in Poland. Higher education in Poland has a nearly 660-year-long tradition, with the origins of the Jagiellonian University (Kraków) dating back to the middle ages. In the last two centuries, the Polish HE sector has been under the strong influence of the German model of Humboldtian university based on Humboldt's ideas of a holistic combination of research and teaching, as well as autonomy and academic freedom from outside constraints. After WWII, in Poland, as in other countries of the region, attempts were made to introduce the Soviet model of HE (publicly held entities centrally planned by the national bureau/ministry, dual control of the state administration and the communistic party apparatus, the use of political loyalty criterion, separating part of the research into an academy of science, and strong involvement in manpower planning). Nevertheless, the strongly embedded Humboldtian ideals, as well as the independent attitudes of many academics ensured some margin of freedom and autonomy. For example, the only private university in the whole communistic bloc survived in Poland—the Catholic University of Lublin (Clark, 1983; Leja, 2013).

Thus, during the transition after emancipation from Soviet dominance, the laws were changed to reinforce Humboldtian autonomy combined with a laissez-faire policy of government. The Higher Education Act, 1990 was very liberal. This law reinforced academic freedom and autonomy, not only in government vs. HEI relations but also in the internal regimens of HEIs. For example, faculties received a high degree of autonomy and independence from rectors. Moreover, the establishment of private HEIs was allowed, as well as the partial introduction of tuition fees in public entities (only for part-time students).

The number of private HEIs then soared tremendously, from only one non-public (catholic) university before 1990 to 328 HEIs held privately by the academic year of 2010/2011. In this peak period, private HEIs accounted for 71% of the whole system, as measured by the number of entities (Godłów-Legiędź, 2016). However, private HEIs are typically small when measured by a number of students. Poland also witnessed a rapid massification of HE. This was not only due to the soaring number of entities established in the private sector but also due to the broadly open gates to public universities, particularly in the form of very popular part-time studies (payable). The percentage of young people studying in the two decades after the transition increased tremendously from nearly 13% in 1988 to slightly over 51% in 2007, when the number of students peaked and approached 2 million (Pietrzak & Gołaś, 2018). The highest ratio of nearly 54% was recorded in the academic year 2010/2011 (Higher education institutions and their finance, 2019).

However, such rapid massification came at a price. The quality of academic education inflated, and job security and rates of return from HE shrank compared to the first years of the boom. Moreover, the problem of demographic collapse began to increase. Just a decade after the aforementioned peak, the number of students dropped sharply by 30% (Pietrzak & Gołaś, 2018) and still continues to decrease.

Recently, the percentage of young people studying was recorded as 46% (Higher education institutions and their finances, 2019), but one should note that the base is lower due to demography. This situation shrank the amount of private money in the system. During the shortage in the supply of tuition-free places in public HEIs, payments for private education or public part-time study solved (in some way) this access problem. However, this demographic collapse transitioned the sector into an oversupply situation. Every year, some privately held HEIs are canceled from the register or go bankrupt. Notably, the peak in the number of private HEIs has a 3-year delay compared to the peak in the number of students. Nevertheless, 10 years after the peak, the number of private HEIs also dropped by nearly 30% (Godłów-Legiędź, 2016; Records of private universities, 2020). Thus, today, the market share of private HEIs has fallen to 64%, as measured by the number of entities, and to 26%, as measured by the number of students (Higher education institutions and their finance, 2019).

The problem with demographic collapse overlaps with the relatively low expenditures on HE in Poland. Such expenditures, calculated as a ratio of the GDP, are only slightly below the OECD average. However, given the relatively low GDP per capita and the relatively high number of students, the annual expenditures per student remain very low. For example, in 2013, the annual per-student expenditure in Polish HEIs was less than USD 9000 compared with the OECD averages of nearly USD 16,000 (Peer Review, 2017).

The revenues of public HEIs in Poland in 2018 accounted for nearly 22 billion PLN,[1] from which 15.7 billion (72% of total revenues) came in the form of subsidies from the central government. These subsidies are divided into funds for maintaining teaching capacity (62% of total revenue) and funds for research activity (10% of total revenue split nearly equally between a direct subsidy connected with the assessment of the university and grants received on the basis of a competition for projects). The rest (28%) of the revenues come from tuition fees from part-time students (11%), international grants, business activities conducted by the HEIs, and other sources (Higher education institutions and their finance, 2019). Governmental control over public HEIs is twofold. Firstly, laws regulate the functioning of HEIs. Secondly, the government steers the money flow. The second aspect is not executed in any discretionary manner by the ministry but is instead regulated by general rules. Moreover, the large money flows are quite inertial due to their connection with such parameters as the number of students. Thus, paying for individual HEI performance is possible in only a limited scope.

Due to the inflation in the status of graduates mentioned above, some social and political pressures have prompted more central control over the HE sector. As a sociological survey showed, the social prestige of the profession of a university professor has decreased. This occupation was, in the past (e.g., 1975), ranked at the highest level (90 points on a 0–100 scale), while presently, it is ranked at 80 points and has been overtaken by such professions as fireman (88 points), nurse (81 points),

[1] At the end of the year 2018, the exchange rate was 1 PLN = 0.2660 USD.

and coal miner (81 points) (Which professions do we respect?, 2019). There are growing concerns about the labor market mismatches and increasing unemployment of graduates. Critics emphasize that despite variations across HEIs, public higher education provisions generally remain supply-driven and poorly aligned to the needs of the labor market. The design and delivery of curricula are based more on academic capacity rather than the demands of the economy (Peer Review, 2017).

Thus, the idea of an entrepreneurial university has started to become more popular. Consequently, many opinion leaders and politicians have begun to advocate the need to abandon the Humboldtian model for the more promising (in their minds) model of the entrepreneurial university. The important reforms of the HE sector in Poland undertaken in the last decade (Act, 2011; Act, 2018) were designed more or less in this vein (Kwiek, 2012; Kwiek, 2017; Pietrzak & Gołaś, 2018). The Act, 2018 yielded some radical changes, which are new and remain difficult to fully assess. From the perspective of our case study, the most crucial act was Act, 2011 and its further amendments, which imposed the obligation of introducing formal strategies for HEIs.

14.4 Choosing the General Approach

The preliminary projects of changes introduced by Act, 2011 were known in advance. The rector of WULS, anticipating these new obligations, delegated the issue of elaborating a strategy to the Rector's Commission of Development (RCD). The RCD is a collegial body (it consists of about 20 people from many units of the university) with competence in advising the rector. I was invited to this commission in the late 2009 as an expert due to my experience in the area of strategic management and Balanced Scorecard (BSC). In the following years, I became a member and vice-chairman of this body.

I suggested that RCD work on a strategy using the project management formula. However, before starting the project, some preliminary decisions and assumptions had to be made. The most important issues were the scope, the methodology, and positioning of the project (and the strategy's execution process) within the organizational structure.

I conducted a survey among top executives of the university. The survey was about the maturity of the strategic management process. I have used to use this survey in business consulting. It consisted of 17 questions related to strategic thinking and execution practices. The possible answers were "no, we certainly have not used such a practice at all"; "no, we rather have not used such a practice"; "yes, we rather have used such a practice"; and "yes, of course we have used such a practice", with nonlinear scoring of 0, 1, 5, and 10 points, respectively. Thus, the results ranged from 0 to 170 points. Typically, in business organizations, which I consulted the results were around 70–90 points. The average result for WULS was 30 points, indicating evident immaturity in the strategic management process.

Based on this result, I suggested two scenarios for the project: an optimal one and an easy one (regarding the scope and assignment of tasks across the organizational structure). In both cases, I suggested the BSC as a methodological basis. In the optimal scenario, I assumed deep involvement of the faculties in strategic formulation and execution.

As mentioned above, during the study, faculties held a strong and independent position, with deans elected by the academic community (staff and students) of a particular faculty. A typical diversified public university in Poland at that time was a federation of relatively autonomous faculties. This indicated that the execution of a strategy for the whole university should rely strongly on the engagement of the deans and the rest of each faculty's staff. Moreover, from a strategic point of view, particular faculties operate under different "market" environments consisting of different types of "customers" and "competitors." They thus have different strengths and weaknesses against their particular environments. This fact highlighted the clear analogy between faculties and strategic business units, as well as between the rector, other top executives, central administrative staff, and headquarters in diversified corporations.

In the strategic management literature, it is strongly emphasized that strategic business units are the parts of any corporation where value is directly created. The headquarters do not directly create value; they create costs. If any value is created by the headquarters, it can only be created indirectly through better coordination of subordinated business units and looking for synergies between them (De Witt & Mayer, 2005; Kaplan & Norton, 2004; Koch, 1995). From this point of view, faculties should have their own strategies. However, the question arises: How can we interconnect the strategies of both layers—the university and the faculty? Four options were identified: a top-down approach, a bottom-up approach, a down-up approach, and a federative/coalitional approach (Fig. 14.2).

In the top-down approach (Fig. 14.2a), vertical coordination is achieved by imposing a strategy for subordinate units. In this method, strategic alignment can be achieved relatively easily. However, this method does not work when the lower layers experience substantial autonomy and are able to resist the expected changes. Due to the strong autonomy of faculties, the top-down approach was not suitable for WULS, like many other Polish universities at that time. On the opposite end is the bottom-up method (Fig. 14.2b), in which faculties elaborate autonomous strategies on their own. Then, the necessary work in the central layer is to synthesize and integrate particular strategies into a strategy for the whole university. The potential advantage of this approach is engagement of the faculties and their staff, the establishment of more achievable and locally oriented goals, and lower resistance to changes. However, this method requires considerable work to implement, complicated by the prerequisite of the high strategic maturity of the lower layers, problems in achieving internal cohesion, and political issues (the faculties were already very strong and independent, making the rector unwilling to give them even more power).

The down-up (top-down/bottom-up) approach (Fig. 14.2c) mixes the two methods described above. At the top layer, the global assumptions and general strategic

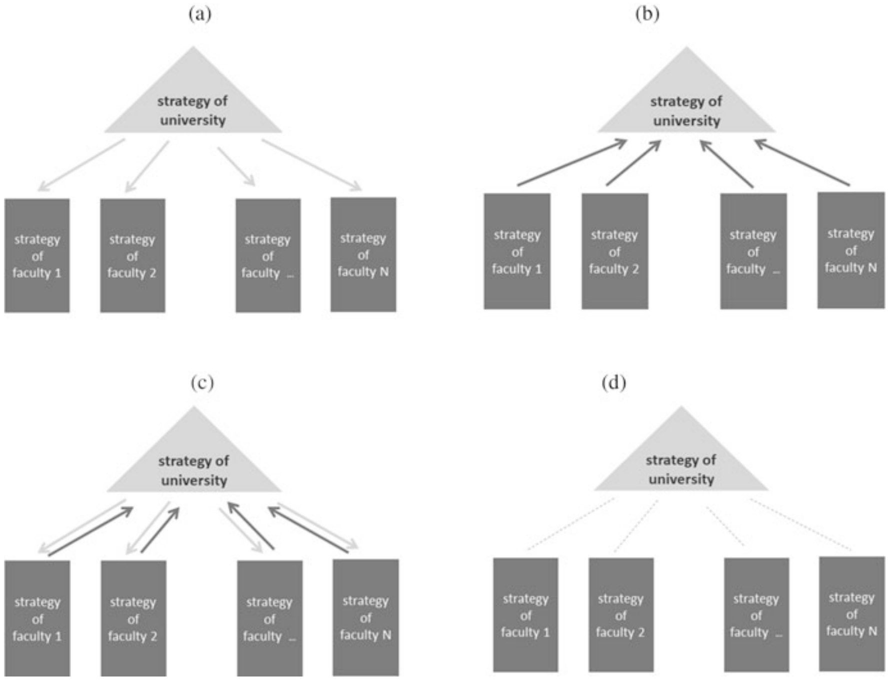

Fig. 14.2 Possible approaches to the vertical coordination of strategies between the whole university and faculty layers. (Source: Own)

intent are defined, while at the bottom, detailed analyses are done, and abilities and limitations are recognized. In this way, strategies in both layers (university and faculty) can emerge as the discussions and negotiations between the two layers progress. Alignment and internal consistency are achieved through engagement and open discussion of the two layers.

Such an approach is strongly recommended in the literature of Hoshin Kanri (the Japanese method of strategic management) and is called "catchball." This term signifies the give-and-take process between and among organizational layers and refers to collaborative goal setting basing on such dialog, which is crucial for people's commitment (Babich, 2002; Cowley & Domb, 1997). The word "catchball" assumes "tossing ideas" (e.g., strategies, metrics, and goals) back and forth to finally find those that are mutually agreeable (Cowley & Domb, 1997). "Catchball" can shed light on possible problems in the capabilities needed to execute a given strategy. If a capability required does not exist, then a breakthrough may be needed. However, the commitment to achieving this breakthrough must be counterbalanced by maintaining control of business fundamentals (Babich, 2002; Cowley & Domb, 1997). The alignment and internal integrity achievable using "catchball" is far beyond the reach of both the top-down and the bottom-up approach. However, "catchball" can be a time-consuming process. Moreover, it requires an attitude of honesty and openness at the bottom, as well as a willingness to listen and trust on the top, which can represent a challenge for the corporate culture of some organizations (Cowley & Domb, 1997).

By a federative approach, I mean acceptance of the loose ties binding the major building blocks united under one umbrella. As Clark (1983) explains, universities operate more like federations or coalitions rather than unitary bureaucratic systems. From this point of view, the whole university is actually a kind of holding company for groups engaged in various areas of expertise.

In the strategic management literature, in opposition to the active attempts to integrate strategies in the company and strategic business unit layers (compare the three methods discussed above), an approach typical for holding structures is also described. De Witt and Meyer (2005) called this the financial control style. Instead of seeking to strictly coordinate the strategies of highly independent units, the headquarters of a holding structure typically limit themselves to imposing some financial goals and restrictions and then simply control them. As mentioned above, the public HEIs in Poland relies heavily on financial support from the government. In the money flow from the government to faculties, the rectors and senates operate as gatekeepers.

Moreover, for HEIs, the symbolic side of the university (culture) can also be considered a kind of a "glue" connecting autonomous faculties (Clark, 1983). As Etzioni (1961) stated, one should make a distinction between coercive organizations (e.g., prisons), instrumental organizations (e.g., business firms), and the normative organizations (e.g., universities and churches). In the last group, a common attachment to ideas predominates over forced compliance and monetary rewards (Clark, 1983). Thus, even without tight ties specific to hierarchical business organizations, and without fully integrated strategies, autonomous faculties could still build a federation under one university umbrella based on financial and cultural relations (compare Fig. 14.2d).

Therefore, as noted previously, two scenarios were proposed: an optimal one and an easy one. In the optimal scenario, I assumed deep involvement of the faculties in strategy formulation and execution by following the down-up ("catchball") approach. However, this ideal approach would come at a cost. I expected that a large amount of time, the involvement of leaders and staff, and support from external consultants would be needed for this method. I prepared a very preliminary draft of such a project and expected that it would take 1.5–2 years to fulfill the tasks based on the serious involvement of many people.

I also presented an alternative in the form of an "easy" scenario. In this approach, the strategy would be prepared only at the university level by the efforts of the RDC members and invited experts from the staff. The issues of the faculties' strategies would be saved for future decisions. In this way, due to the efforts of a limited number of people (mostly members of RDC), we could develop a strategy within half a year, and we would produce a document based on a state-of-the-art methodology (BSC model), which will fulfill the obligations of the law. Moreover, by doing this, we could also ensure the option to further develop the strategic management system. In other words, this work not only would allow us to follow external obligations but would also give us the right (but not the obligation) to further expand the strategic management system if needed. It was decided that WULS would follow the second scenario, despite not being the most optimal method.

14.5 Defining the Project

After the main approach to the strategy was clarified, the RCD started to work on the project “Development of the WULS strategy based on Balanced Scorecard.” Authorities of WULS declared that they were not fully satisfied with the current documentation of the strategic assumptions for the university’s development. Thus, they formulated in the project charter an expectation that the transparency and consistency of the assumptions underlying strategic development had to be updated and improved. Additional expectations concerned building a methodological basis for the eventual future development of the strategic management.

Regarding the project scope, these results were planned to be achieved by conducting a SWOT analysis, defining the mission, vision, and expression of these assumptions in the form of a strategy map of WULS along with a set of measures for strategic goals. To fulfill the abovementioned expectations and to complete these tasks, the following roles were defined as the responsibility assignment:

- Project sponsor (rector): Ownership of the project, final acceptance of products / milestones of the project, and building support for the project.
- Steering committee (RCD): Strategic control of the project and pre-approval of the project outputs / milestones.
- Project manager (former rector): Direct organization, coordination, and control of the project, supplying results, and editing the final document.
- Project expert (the present author): Providing know-how in the field of strategic management and BSC and editing final document.
- Project team (members of RCD and invited specialists from the staff): Obtaining and analyzing the necessary information.
- Project secretary: Documenting the work of the team.

14.6 Mission, SWOT, and Vision

For any analysis, the preliminary step should be to answer the following questions: What is the analysis for, and what should be the scope of the analysis? Thus, before a strategic analysis of any organization is carried out, the raison d’être of such an organization and the basic scope of its activities should be defined. In other words, the whole process of strategic management should begin with a formulation of the mission. The mission is understood as the purpose of the organization, which describes why it exists. The mission typically defines the scope of the organization's activities and/or identifies its fundamental needs, which is fulfilled by specifying what the organization provides to customers and clients or citizens and beneficiaries (Babich, 2002; Cowley & Domb, 1997; Kaplan & Norton, 2008). Missions are typically supplemented by value statements that define the fundamental beliefs, attitudes, and characteristics that should drive decision-making and behavior (Cowley & Domb, 1997; Kaplan & Norton, 2008).

Interviews were conducted with the rector and vice-rectors, the chancellor, and living former rectors regarding their perception of the raison d'être of WULS, the desired scope of the disciplines covered, and the beneficiaries served. They were also asked about how they perceived the school's fundamental values, which they believed should drive the actions of the academic community of WULS. The results of this survey were discussed by the project team; following this discussion, a draft statement of the school's mission and values was prepared. After acceptance by the rector, this draft was voted by the senate as part of the strategy document. The final version is presented at the top of the strategy maps in Fig. 14.5.

The next step was a strategic analysis prepared based on the SWOT (Strengths-Weaknesses-Opportunities-Threats) framework, which is one the most popular strategic tools for managers. This tool provides an overall picture of what a particular factor means for an organization, as strengths, weaknesses, threats, and opportunities must be framed by intentions (Spender, 2014). This is why the mission should be defined first. According to the seminal paper of Lewin (1947), any social situation can be seen through the lens of force-field analysis as the quasi-stationary equilibrium between driving and restraining forces. If we additionally consider the internal and external characteristics of such forces, we can easily understand the essence of SWOT. Strengths are internal resources, processes, and other issues in which the organization is proficient and, therefore, could serve as strategic leverage for mission fulfillment. Weaknesses represent the opposite—obstacles to mission fulfillment, which close the windows of opportunities and expose the organization to threats. Opportunities and threats are forces in the external environment of organizations and are perceived as supporting and hindering, respectively, the mission fulfillment.

The project team identified 216 SWOT issues, including 54 strengths, 84 weaknesses, 31 opportunities, and 47 threats. Overall, this assessment was rather pessimistic (weaknesses and threats accounted for 61% of all issues) and internally focused (strengths and weaknesses were 64%). The typical problem with SWOT analysis is that the analytics often define issues in a very general manner—For example, an organization might note that "our strength is our people." However, what makes those people a strength? What do we expect to get from them? A much

Table 14.2 Excerpt from the SWOT issue list and the explanation of how each issue was used in defining the strategic objectives in the strategy map

Strengths	Weaknesses	Opportunities	Threats
• Localization in capital city where big corporations and central administration offices are also located (*fact*)—competitive advantage against smaller academic centers (*implication*)	• Localization in capital city where the costs of living are high (*fact*)—relative cost advantage of smaller academic centers against us (*implication*) • Limited capacity of dormitories (*fact*)—difficulties in attracting candidates from remote regions (*implication*)	• Low costs of studying in Poland relative to the countries of the "old EU" (*fact*)—international cost advantage against western European HEIs (*implication*)	• Strong position of private HEIs in very small cities which never had academic traditions before 1990 but which are proximal to the parents' households (*fact*)—cost advantage even against regular public curricula (no fees) when taking into account the cost of living in the big city and even more in the case of payable part-time curricula at public HEIs (*implication*)
↓	↓	↓	↓
Strategic objective I7: Decreasing the total costs of studying			

Source: Own elaboration based on notes from project team meetings

more useful statement of strength could claim that due to the depth of experience, the sales force gives an organization credibility in the market, which makes it more likely to attract new customers (Smith, 2007). In such a statement, there are two components: the fact (experience of salespeople) and the implications of the fact (the credibility and likelihood of new accounts). We followed the suggestions of Smith (2007) and formulated each SWOT issue statement in this way (compare Table 14.2). We also divided all SWOT issues across perspectives of the BSC. Following both these suggestions aided subsequent steps of the project.

The vision depicts an ideal future that is inspiring and empowering. The essence of such a statement is to articulate what an organization wants to be when it matures in a 3 to 10 years horizon (Cowley & Domb, 1997; Kaplan & Norton, 2008; Smith, 2007). Kaplan and Norton (2008) proposed an approach to the vision statement, which they call "enhanced vision." This approach provides a comprehensive picture of how an organization wants to be perceived based on the basic BSC architecture considered from four perspectives.

We followed this idea but modified the original model of the BSC. According to Niven (2008), the BSC, with some modifications, could be a useful tool for public sector organizations. It could be particularly useful in HEIs, which is widely shown in the literature (Asan & Tanyas, 2007; Juhl & Christensen, 2008; McDevitt et al., 2008; Papenhausen & Einstein, 2006; Tapinos et al., 2005; Umashankar & Dutta, 2007). Regarding universities in the United Kingdom, Taylor and Baines (2012) emphasized that the BSC model should be adapted to the specific mission and circumstances of any HEI.

Due to the specific nature of public universities, it is difficult to treat the financial perspective as the ultimate definition of success. Thus, the commercial logic of the original BSC model should be modified. One suggestion of the authors of the BSC concept (Kaplan & Norton, 2004) is that the mission should move to the top of the framework, thereby replacing the financial perspective as the ultimate definition of success. This is because the success of public and nonprofit organizations is defined by public/social impacts according to their missions. Such organizations make attempts to meet the needs of people who benefit from the services supplied by them, who could be called their customers (or, more accurately, stakeholders). Thus, Kaplan and Norton proposed to elevate the customer (or stakeholder) perspective to the same level as the financial one (renamed as the fiduciary perspective). In this way, both perspectives should be treated as equally important. The customer and fiduciary perspectives are supported by two further ones: the internal process perspective and the learning and growth perspective.

Niven (2008) offered a different modification. His proposal is only slightly similar to that of Kaplan and Norton, as he also suggested moving the mission to the top of the BSC framework. However, in comparison to the commercial model of BSC, Niven proposed a reverse framework. In Niven's adaptation, the customer perspective is elevated while the financial perspective moves to the bottom of the framework. Elevating the customer (or stakeholder) perspective signals that anything done from other perspectives is done to support the customers/stakeholders. On the other hand, the achievement of financial goals is not the ultimate goal but will help serve stakeholder demands and, therefore, provide a means of fulfilling the mission.

According to Smith (2007), the choice of a proper modification depends on the specific culture and circumstances of any particular organization, as an organization should choose the framework of the BSC that facilitates explaining its strategic intent in the desired way. This reasoning also extends to the names and even the numbers of perspectives (Smith, 2007). According to Taylor and Baines (2012), British universities adopted the names of the original perspectives of the BSC and used their own labels.

The project team chose Niven's (2008) proposal. The mission was thus moved to the top as the ultimate definition of success for WULS. The customer (stakeholders) perspective was elevated, while the financial perspective was moved to the bottom of the framework. Moreover, we changed the names of the perspectives: "customer" into "stakeholder" and "learning and growth" into "potential perspective." Figure 14.3 presents the enhanced vision of WULS in 2020 as it was defined ten years ago within a modified architecture of perspectives.

Perspective	What we want to look like in an ideal future
Stakeholders	➢ Better quality of candidates while maintaining their numbers ➢ More research projects, including large and prestigious projects ➢ Stronger bonds with business practice as a partner in research and advisory services
Processes	➢ Greater student mobility and offering competences useful on the labor market ➢ Making the university more student-friendly ➢ Increased activity in the academic community at home and abroad, greater international visibility of research ➢ Transfer of knowledge to the business as an equivalent sphere of activity to teaching and research
Potential	➢ Academic staff—mobile, ensuring a dynamic academic career ➢ Management of the University—continuation of the changes transforming WULS into a modern third generation university united around its traditional core of life sciences; effective implementation of the strategy and change management ➢ Infrastructure—further development of research, teaching, and social facilities, the provision of an R&D unit and adequate development of IT infrastructure
Financial	➢ Stable financing of activities due to an increase in revenues other than subsidies from the Ministry of Science and Higher Education and due to the improvement of cost effectiveness

Fig. 14.3 Extended vision of the Warsaw University of Life Sciences in 2020. (Source: Own)

14.7 Strategy Map

Due to the traits of the human brain and its limited capacity for processing and memorizing information, human actions are plagued by bounded rationality (Simon, 2000; Witt, 1998, 1999, 2005). To cope with this limitation, people use cognitive frames. The organizational strategy is always a multi-person activity based on collaboration. Thus, leadership can be seen as a provision of cognitive frames. A strategy expressed in any way is a kind of cognitive frame that must be transmitted to and adopted by members of an organization to successfully execute that strategy (Witt, 1998). Therefore, the strategy must be based on a shared mental model or shared organizational theory-in-use (van der Heijden, 1998).

Any novel idea or conception requires acceptance from those who could implement that idea. For it to gain acceptance, the strategy must be communicated. Moreover, before people can execute the strategy, they must accept it (Kaplan & Norton, 1996, 2001; Niven, 2005). Therefore, a coherent story (a narrative that explains what is happening and how the current situation will be changed or improved) is needed to induce the commitment needed to execute the strategy.

Strategic narration should express the aspects (see Fig. 14.4) that are crucial for survival and development (van der Heijden, 1998). In the BSC methodology, this story is the content of the strategy map (Kaplan & Norton, 2004). This story can be understood as a one-page picture that shows the paths of the organization's movement from the present situation to the desired future. Strategy map outlines

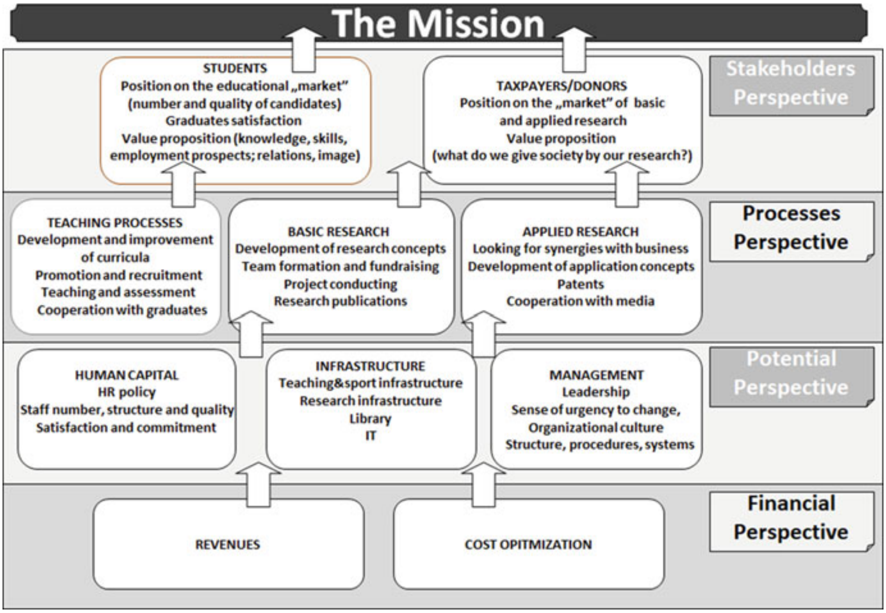

Fig. 14.4 Detailed BSC framework for HEI adopted by WULS. (Source: Own)

what the organization has to do to successfully execute its strategy (Niven, 2008). The crucial feature of a strategy map is its simplicity—a one-page picture visualization depicts the story that explains how the organization defines its success and signals to employees what must be done (Niven, 2008; Smith, 2007). A strategy map can be seen as a communication tool and cognitive pattern for members of the organization and is helpful for building commonly shared mental models of the organizational destination (Pietrzak, 2014a, 2017).

The strategy map consists of two elements. The first element involves the strategic objectives put into the map as ovals with short statements inside. Objectives are linked together through cause-and-effect relations (represented in the map by arrows). They are not treated as independent elements here but as a whole that expresses the overall strategic intent of the organization. Such a map creates a visualization of the strategy, highlighting the path necessary for the successful implementation of the strategy.

In drawing the strategy map, the project team used the results of the SWOT analysis. These results were useful for outlining both facts and implications of the facts. As mentioned above, the SWOT issue statements were divided across four perspectives. In each perspective, they were further clustered into coherent groups. Clustering was based on the "fact part" of the statements in such a way that the grouped issues could cohesively fall under an umbrella of a common problem to be solved. Then, a short statement about the desired direction of action was formulated and put into an oval (for overcoming weaknesses and threats, leveraging strengths,

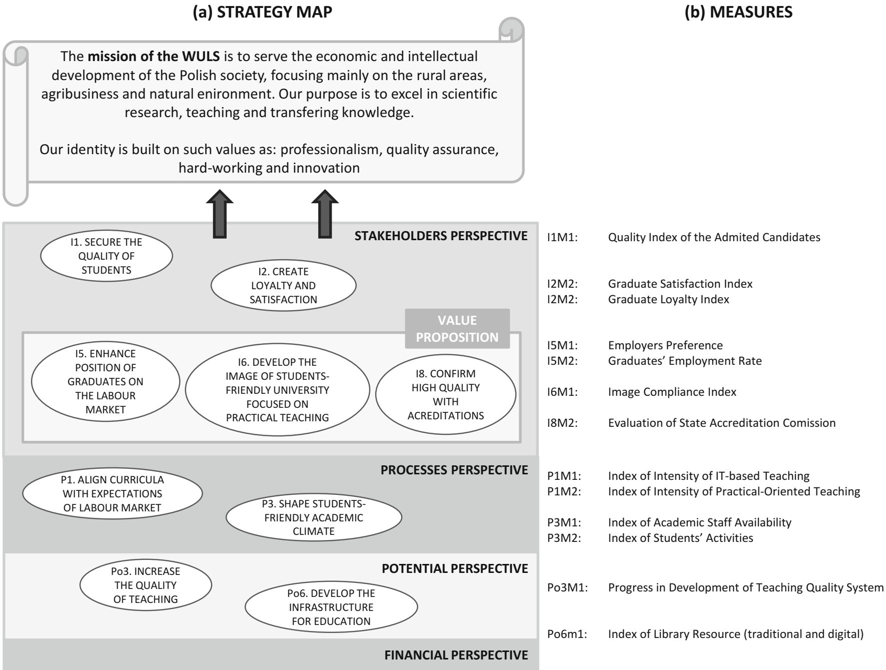

Fig. 14.5 Excerpt from WULS strategy map (Theme 1: Improving Teaching). (Note that the measures were indexed as follows: The first part of the index denotes the perspective (I—Stakeholders, P—Processes, Po—Potential) and the ordinal number of the objective in this perspective; the second part of the index denotes the ordinal number of the measure tied to this objective, e.g., P1M2 denotes the second measure of the first objective in the Process Perspective. Source: Own)

and seizing opportunities; compare Table 14.2[2]). Secondly, when the list of strategic objectives was ready, the project team drew arrows that illustrated the expected cause-and-effect relations between the strategic objectives. To perform this task, the "implication of the fact" portions of the SWOT issue statements were useful.

Based on the modified framework of BSC (Fig. 14.4) and following the method outlined above, the strategic map of WULS was drawn, and 216 of the SWOT issue statements were transformed into 30 interrelated objectives on the map (Borecki & Pietrzak, 2010). Figure 14.5a depicts an excerpt of this strategy map. Kaplan and Norton (2004, 2008) suggested dividing the strategy map into several (four to six) building blocks, which they called "strategic themes." Each of these themes supports strategy execution in a different but complementary way. We followed this

[2]Objective I7 (an example from Table 14.2) was abandoned during one of the strategic reviews. This objective was formulated using the logic of competition with a private HEI. However, as explained in Sect. 14.9, the incentives created by the government generated the opposite logic. The arbitrary limit of the students per academic staff ratio enforced by the government created a lack of interest among public HEIs in gaining a "market share" in the teaching sector.

proposal by identifying five such components: theme[3] 1—Improve Teaching, theme 2—Excel at Research, theme 3—Cooperation and Internationalization, theme 4—Enhance Cooperation with Business, and theme 5—Finance and Administration. Figure 14.5a illustrates one such theme.

14.8 Operationalization and Further Development

To make the strategic objectives more operationalized, one or more measures were assigned to each of them (Fig. 14.5b). The essence of any measure is to answer the question, "How will we know that we are moving where we want to go?". Firstly, I prepared a long list of possible measures based on my consulting experience, a review of the literature, and a discussion with the project manager. In the first round of assessment, every member of the RCD offered his/her own rating (for a particular objective) of the proposed measures. It was also possible to put into the list own proposal of a measure. Then, a shortlist of measures was created, which consisted of two (per objective) winners of the previous round, as well as additional proposals included in the list by relevant members (where applicable). In the second round, all measures from the shortlist were discussed and finally ranked again. The winners became part of the BSC. In cases where consensus was not achieved or where serious difficulties in measurements existed, two measures per objective were allowed. The BSC of WULS ultimately consisted of 30 objectives and 49 measures.

Following Niven's (2002) advice, we prepared a dictionary of measures, a document that provides all members of the organization involved with a detailed examination of every BSC measure. We used this dictionary to define such aspects as the measures and their formulae (how they are calculated), the rationale for using each measure, and each measure's polarity and denomination.

The operationalization of the strategy did not go beyond assignment and definition of the measures. There were no targets established with detailed timelines. The majority of RCD members argued that for many measures, the required data were not collected, so the information on such measures should first be collected and then interpreted before setting targets. In the opinions of these members, gathered information should be the baseline for establishing targets in the future. As the years have passed, reality has shown that this was only partially true. Only some of the objectives had targets assigned, and even in these cases, those definitions took the form of referential values due to a lack of timelines. There were no strategic initiatives (projects focused on target achievement) defined. Such projects are collections of finite-duration discretionary tasks outside the organization's day-to-day operational processes that are designed to help an organization achieve its targets (Kaplan & Norton, 2008).

[3]Thus, the hierarchical structure of the strategy is as follows: mission and vision-strategy map-strategic themes-strategic objectives-measures of objectives.

The mission statement, the extended vision, the strategy map, and the dictionary of the measures were subject to voting by the senate. After voting positively, this document began to be communicated to the academic community and external stakeholders. The strategy was printed by the WULS publishing house (Borecki & Pietrzak, 2010) and was also available on the website of the university.

Meanwhile, the faculties of WULS were obliged to initiate their own efforts in preparing strategies. This process, however, was not centralized. Faculty authorities engaged in this process individually, based on the foundations of the WULS strategy. Considering the discussion above, this process was conducted in a loose federative manner (compare Fig. 14.2d). There were no obligations to use any specific framework or methodology. The only central requirement for the faculties was to develop a strategy compatible with, and supportable by, the top strategy. Up to the end of 2013, all 13 faculties developed their own strategies. However, there was no process to formally control the coherency of the strategies in these two layers (university vs. faculties).

The assignment of measures to the strategic objectives allows one to report performance and monitor the progress of strategy implementation. After its approval in 2010, every year, the progress in strategy execution, as indicated by the measures, was reported to the senate by the RCD. There were some changes made as time passed. In 2013, the strategy was modernized due to an amendment of the law. In the new map, developed after the update of the strategy, the number of objectives was reduced to 27. However, the number of measures increased to 57. Meanwhile, an increase was observed in consciousness of the need to reduce the number of objectives and measures. Some of the measures were abandoned due to the yearly reviews.

In 2018, a new law regarding HE was introduced by the new government. Preliminarily, an idea was formed to modernize the established strategy in a substantial way due to these changes. I prepared a draft of a new strategy map and a set of measures. In this draft, the number of objectives was reduced to 15, while measures were reduced to 38. However, the reform induced so many serious changes (a number of radical changes in the organizational structure) that there was no will to continue this idea, and the "old" version of the strategy with some slight modifications was reported until the end of the term of the WULS authorities and the end of the strategy horizon (the same time, 2020). New authorities were recently elected, and reforms under the new law have already been introduced. Thus, a new strategy in this new context will likely be prepared soon.

14.9 Objective Results: Benchmark Analysis

To assess the application of BSC in WULS, one can start with facts and figures. A longitudinal comparison of the state of affairs "before" and "after" implementation is the most natural way to do this: is the present conduct and performance of WULS better than before? Which areas of functioning in this HEI have improved? Have some of them become worse?

However, if any element has improved, is the improvement sufficient? On the other hand, if something has become worse, is this result due to failures of the HEI or due to external changes and limitations, e.g., legal restrictions? Thus, the presentation of some changes in figures will be much more informative when done in the correct context. Following this idea, I selected two benchmarks.

University of Warsaw (UW) was selected as the first benchmark. This institution is the biggest and the best HEI in Poland. In some rankings, this HEI is sometimes outperformed by Jagiellonian University in Kraków, but UW still remains the most natural point of reference for other HEIs in Poland. Moreover, due to its localization in the same city, UW is also a serious competitor for WULS. There are several identical or similar teaching and research areas between both WULS and UW; nevertheless, WULS has a clear focus on life sciences. There are four other universities in Poland (Poznań, Wrocław, Kraków, and Lublin) with similar focuses. There are also four other HEIs that had a similar focus in the past, but since gravitated strongly into other areas or even merged with other universities; thus, they were not taken into account. Each of the universities from the four cities mentioned above represents about 40–50% of WULS' potential, as measured by the number of students. Among these schools, I chose Wrocław University of Environmental and Life Sciences (WUELS) due to the availability of data needed to perform comparisons.

There is a significant problem with the availability of comprehensive data on HEIs in Poland. Theoretically, there are some legal obligations for reporting, but not all HEIs ensure open access to their reports. Moreover, these reports have tremendous diversity in their scope and the ways in which data are presented. Therefore, it is difficult to obtain a comprehensive and comparable dataset. Nevertheless, Tables 14.3 and 14.4 present such a dataset. Although limitations remain in the dataset, some interesting observations can be made.

Regarding potential, the relative weakness of WULS compared to UW seems to be WULS' excessive number of nonacademic staff (55% vs. 49%), which could lead to an unnecessary increase in overheads. This could also be one of the reasons for the lower dynamics of salaries and relatively high share of labor costs in the total costs. On the other hand, WULS has a greater share of professors in its academic staff than UW (in WUELS, this share is even higher). However, this share in WULS is slightly decreasing. In terms of material potential, WULS clearly outperforms in two benchmarks. Even though the net value of the buildings owned by WULS decreased (due to depreciation), in a relative sense (e.g., per student), the value is still much higher than that in the benchmarks. It is commonly known that WULS has the best and the most cohesive campus in Warsaw, possibly even in the whole country. This is due to the large investments made in the previous decade, which were financed from selling some parcels of land owned by WULS. As the land vs. building ratio indicates, there is still some space for potential investments of this type in the future. Such investments, however, are not easy to conduct because of the need to receive an allowance from the government. Nevertheless, this was done in

Table 14.3 Key data about WULS and its benchmarks

Area	Item	WULS		WUELS		UW		WULS	WUELS	UW
		2009	2019	2009[a]	2019[b]	2009[c]	2019	CAGR (%)	CAGR (%)	CAGR (%)
Potential	Total employees [persons]	2713	2690	1579	1640	6023	7498	−0.1	0.4	2.2
	Academic staff [persons]	1243	1198	700	738	3159	3834	−0.4	0.5	2.0
	Professors [persons]	269	239	177	209	435	529	−1.2	1.7	2.0
	Salaries [mln PLN]	164.5	247.7	82.3	149.6	431.3	716.0	4.2	6.2	5.2
	Assets [mln PLN]	2040.0	2092.0	385.1	430.6	1788.4	2468.6	0.3	1.9	4.7
	Land [mln PLN]	1151.0	1162.6	92.5	91.5	435.8	541.1	0.1	−0.2	3.1
	Buildings [mln PLN]	748.0	589.4	215.7	240.4	556.1	960.8	−2.4	1.8	8.1
	Equipment [mln PLN]	23.3	31.6	17.9	15.2	98.8	95.1	3.1	−2.7	−0.5
Teaching	Students [persons]	24,532	16,070	10,096	8076	55,387	40,493	−4.1	−2.2	−3.1
	Regular students [persons]	14,272	11,056	7609	7238	31,305	31,153	−2.5	−0.5	0.0
	Part-time students [persons]	10,260	4124	2487	838	24,082	9340	−8.7	−10.3	−9.0
	Graduates' (BSc, BA) salary [kPLN][d]	na	3.35/3.97	Na	2.50/3.12	na	3.49/4.22	na	na	na
	Graduates' (MSc, MA) salary [kPLN][d]	na	4.18/4.23	Na	3.10/3.30	na	4.34/4.45	na	na	na
Research	External grants for research [mln PLN]	na	36.1	11.1	17.7	76.4	227.3	na	4.8	11.5
	Publications [#]	na	2216	757	1069	6869	5199	na	3.5	−2.7
	Citations (WoS) [#]	3848	27,227	na	na	na	na	21.6	na	na
	Faculties with A or A+ category [#]	6	6	na	3	na	15	0	na	na
Finance	Revenues [mln PLN]	293.3	510.6	164.9	313.0	859.6	1651.5	5.7	6.6	6.7
	Costs [mln PLN]	292.7	475.6	152.9	259.3	846.3	1559.4	5.0	5.4	6.3
	Net Profit [mln PLN]	−2.2	36.9	11.8	53.7	15.9	93.9	–	16.4	19.4

CAGR—Compound annual growth rate depicts the ratio of average dynamics over the year

Source: Appropriate reports of rectors, annual financial statements, Graduate Tracking System, and the author's notes from project team meetings (regarding citations in WULS)

[a] Asset values for the end of 2011

[b] Asset values for the end of 2017

[c] Asset values for the end of 2012—calculations of CAGR were adjusted as needed

[d] Average monthly gross salary in the first and fifth year after graduation (data for graduates from 2014 and from 2018)

Table 14.4 Key indicators for WULS and its benchmarks

Area	Item	WULS		WUELS		UW	
		2009	2019	2009[b]	2019[c]	2009[d]	2019
Potential	Academic staff share in employee numbers [%]	46	45	44	45	52	51
	Professors' share in academic staff members [%]	22	20	25	28	14	14
	Average salary [kPLN per person]	60.6	92.1	52.1	91.2	71.6	95.5
	Salaries' share in costs [%]	56	52	54	58	51	46
	Salary and social security share in costs [%]	69	65	na	na	60	58
	Equipment per employee [kPLN per person]	8.6	11.7	11.3	9.3	16.4	12.7
	Equipment per academic staff member [kPLN per person]	18.7	26.4	25.6	20.6	31.3	24.8
	Buildings per student [kPLN per person]	30.5	36.7	21.4	29.8	10.0	23.7
	Land vs. building ratio [#]	1.5	2.0	0.4	0.4	0.8	0.6
Teaching	Students per academic staff [#]	19.7	13.4	14.4	10.9	17.5	10.6
	Part-time students share [%]	42	26	25	10	43	23
	Graduates' (BSc, BA) relative salary [%][a]	na	67/86	na	54/74	na	64/82
	Graduates' (MSc, MA) relative salary [%][a]	na	85/94	na	66/79	na	81/91
Research	External grants per academic staff member [kPLN per person]	na	30.1	15.9	24.0	24.2	59.3
	Number of publications per academic staff member [#]	na	1.8	1.1	1.4	2.2	1.4
	Number of citations (WoS) per academic staff member [#]	3	23	na	na	na	na
	Share of faculties with A or A+ category [%]	46	46	na	60	na	71
Finance	Revenues per employee [kPLN per person]	108.1	189.8	104.4	190.9	142.7	220.3
	Revenues per academic staff member [kPLN per person]	236.0	426.2	235.6	424.1	272.1	430.8
	Net profit per employee [kPLN per person]	−0.8	13.7	7.5	32.7	2.6	12.5
	Net profit per academic staff member [kPLN per person]	−1.8	30.8	16.9	72.8	5.0	24.5

Source: Appropriate reports of rectors, annual financial statements, Graduate Tracking System, and author notes from project team meetings (regarding citations in WULS)

[a]Gross salary in the first and in the fifth year after graduation (data for graduates from 2014 and 2018) as a percentage of average salary in the region of residence

[b]Asset values for the end of 2011

[c]Asset values as for the end of 2017

[d]Asset values for the end of 2012

the past and is thus possible in the future if needed and also creates some advantages in material potential. Moreover, in the case of equipment, WULS exhibits a positive dynamic (compared to the benchmarks), and, in 2019, had the highest indicator of equipment per academic staff.

Regarding teaching, WULS performs well against its counterparts. The number of students decreased spectacularly, but decreasing numbers were also observed in WUELS and UW. All these changes were enforced by regulations from the government. Due to these regulations, public subsidies are strongly tied to the student per academic staff member ratio. The threshold of 13 was established arbitrarily, and HEIs that do not maintain this threshold were punished by the loss of some subsidies. Before this regulation, public HEIs experienced incentives to treat this relation as a kind of efficiency indicator (the higher the better) due to the additional money from the government for each regular student or the additional tuition fees from each part-time student. This new regulation was argued to be an attempt to improve teaching quality, but this mechanistic and arbitrary approach seems suspect. Nevertheless, the decrease in student numbers was not a failure but the result of the government's enforcement of the regulation.[4] The higher dynamics in this decrease observed in WULS were due to its stronger base at the outset.

WULS does well in teaching. This factor can be objectively verified by the data from the Polish Graduate Tracking System (GTS). GTS collects data from the Social Insurance Institution and national register of students and graduates, covering the entire population of graduates. The average salary of WULS graduates is evidently higher than that of its counterpart in the life sciences area and very close (94–96%) to the salary of graduates of the most prestigious university in Poland (UW). As measured in relative terms, the situation is even better. Regarding the average salary in the region of residence, graduates of WULS outperform not only WUELS but also UW.

For research, the results of WULS are more ambiguous. Even though WULS receives more external funds than WUELS, the amount is still nearly two times less than that of UW, as measured per academic staff member. However, this situation should be viewed in a broader context. In Polish science, we can observe the phenomenon called the Matthew effect (which takes its name from the parable of the talents from the Gospel of St. Matthew) or the accumulated advantage effect, which involves giving greater recognition for scientific contributions to researchers of considerable repute and withholding such recognition from researchers who have not yet made a substantial contribution (Merton, 1968). The original observation of Merton can also be extended into the financial domain, where the rich become richer, and the poor become poorer (Bornmann et al., 2020). For example, in Poland, funds for basic research are assigned mainly by the National Science Centre according to competitions for grants. In 2011, only two out of 210 competitors, namely UW and Jagiellonian University in Kraków, acquired 14% of the total

[4] Some critics suggest that this is due to helping private competitors by giving them a substantial "market share" for free.

funds. In 2019, these universities gained 24% of the total funds. For WULS, the numbers were 0.5% and 0.9%, respectively. In absolute terms, the progress was even greater—from 2.5 to 11.6 million PLN (Dynamic statistics, 2020). Nevertheless, even such noteworthy progress was marginal compared to the gains of the biggest HEIs.

As mentioned previously, public HEIs in Poland are assessed by their research performance and subsidized accordingly. As a result, each faculty or other research entity is classified as A+ (the best), A, B, or C (the worst). Six out of 13 faculties (46%) of WULS are categorized as A or higher, WUELS has 60%, and UW 71% of such faculties. Nevertheless, WULS outperforms its benchmarks regarding the number of publications per researcher. This indicates a very high annual rate of increase (nearly 22%) in the number of citations (according to the Web of Science); there was also progress made in the internationalization and quality of these publications.

Regarding finance WULS maintains proper dynamics of cost vs. revenue, which helped improve its profit results, which were negative in 2009. The average growth rate of WULS's revenues was higher than the dynamics of the Polish GDP. However, this growth rate was still slightly lower than that indicated only by benchmarks.

To sum up this analysis of the objective results, WULS did not achieve amazing success. However, it also did not completely fail. Overall, WULS maintained pace with its counterparts with a tendency to outperform them in effectiveness of teaching but it has a rather weaker position in research.

14.10 Challenges and Lessons Learned

A qualitative assessment of the implementation of this strategy and the Balanced Scorecard by WULS can be done from at least three points of view: external, internal, and methodological. Establishing this strategy was enforced externally by law (Act, 2011). This new obligation was formally fulfilled. Moreover, WULS executed this strategy quite well (regarding the strategy's preparation and content) compared to other public universities.

As previously mentioned, the above strategy began to be developed in 2009 and was approved by the senate in 2010. According to the research done by Jasiczak et al. (2011), in 2011, only 35 out of 132 public HEIs (27%) had already developed a strategy or were just starting to do so. In total, 39% had mission statements, while only 7% had visions. A few years later, these statistics improved slightly. According to the research of Piotrowska-Piątek (2015), 59.3% of public HEIs had formal strategies: 57.5% of these documents consisted of mission statements, 33.3% included visions, 27% included a SWOT analysis, and 84.8% included strategic objectives. However, the objectives were rarely operationalized: Only 42.4% of these documents consisted of measures, and 54.5% of them defined ways to achieve their goals. Around 12% of public HEIs used modern methods, in such number Balanced Scorecard (Piotrowska-Piątek, 2015). Regarding BSC's implementation in Polish HEIs, the literature is scarce. Due to my best knowledge, there are only four cases mentioned in other papers (Chęś & Lewandowska, 2013; Jaworski & Woźny, 2015; Lewandowska & Zygarłowski, 2014; Piasecka, 2013; Pietrzak, 2014a; Świerk, 2014; Świerk & Mulawa, 2015). Three of these case studies involve public HEIs—namely, WULS, University of Bielsko-Biala (UBB), and Maria Curie-Sklodowska University in Lublin (UMCS), as well as one private HEI, TEB Akademia (Group of WSB Universities). TEB Akademia is an interesting case of a network of private HEIs growing dynamically (now it accounts for nearly 80 thousand students, comprising over 20% of the market share among private HEIs); however, it represents the private sector.

No papers were found on the details of BSC's implementation in UBB; however, analysis of the content of the strategy document for the years 2012–2020 indicates a rather superficially elaborated methodology with only 31 strategic objectives established (without any measures), split across 4 perspectives (Growth strategy, 2012). This model was possibly more developed in other documents that are not available to the public. BSC's implementation in UMCS was much more transparent: it was briefly summarized in three papers (Piasecka, 2013; Świerk, 2014; Świerk & Mulawa, 2015) and explored in the much more profound way by Ernst and Young (EY), a consulting company that was engaged in this project (Ernst and Young, 2011a, 2011b, 2011c, 2011d, 2012). The documentation presented by EY is large-scale (BSC was cascaded into faculties and into support units), deeply elaborated, and well-formed from a methodological point of view. The strategic planning horizon in these documents was 2021. I did not find any elaboration or assessment of this implementation from a present-day perspective, but a new UMCS strategy prepared for the years 2019–2025 was already approved by the senate (Strategy of Maria Curie-Skłodowska University, 2019). It seems to be symptomatic that in these documents BSC is not even mentioned, nor strategy map, perspectives, cascading, etc.

To summarize this assessment from an external point of view, WULS met the governmental requirements and prepared a formal strategy. Moreover, it did so basing on a modern methodology borrowed from the business sector and adapted to sectoral and local specificity. According to the short discussion above and comparative research done by Pietrzak (2014a) and Pietrzak and Gołaś (2018), the WULS strategy looks well compared to the strategies of other public HEIs in Poland.

However, a skeptic could ask if there is any proof that, considering all this involvement of public HEIs all around Poland in strategy formulation, was the social welfare of the nation significantly enhanced? This question will be difficult to answer. I am an enthusiast of strategic management. However, to work well this process requires an owner. As explained above, public HEIs rely heavily on public funds. Consequently, the government consistently attempts to somehow modify the behavior of HEIs. The law enforced the elaboration of strategic documents. Nevertheless, there were no institutions or mechanisms to determine real accountability under this strategy. Moreover, the government did not act as a nationwide owner of such strategies. Notably, on a macro scale, this situation mirrored the problem of strategy cascading at WULS. In both cases, the problem was the high degree of autonomy of the lower layers combined with a lack of developed mechanisms for strategic harmonization.

In the business sector, the accountability for strategies is executed twofold—by competition on the marketplace (markets for outputs and markets for inputs) and by internal corporate governance (board of directors, general meetings of shareholders, etc.). These two methods failed in the case of the public HE system in Poland. Thus, the first lesson learned is that a reasonable implementation of a strategy in public HEIs requires the development of a nationwide system of governance and accountability as a prerequisite.

The assessment of the WULS case from an internal point of view is also ambiguous. Some drawbacks and limitations of our strategic efforts are already obvious for readers. Some limitations are also outlined in the methodological assessment section. However, BSC implementation also had some positive results from an internal perspective. There was substantial progress in some (but not all) important strategic directions. The project itself and reporting based on BSC increased strategic awareness and maturity. Many staff members learned about strategic management and modern frameworks like Balanced Scorecard. Some innovative measures were also defined and established. Even though the implementation had drawbacks and limitations, it could be understood as an option for future action. The experience gathered and methodological foundations constructed could yield positive results in the future, if a new strategy is prepared. The new institutional context in Poland seems to be more "strategy-friendly" than it was in the past. The new law (Act, 2018) increased the power of rectors and substantially reinforced their position against deans. It also created new bodies in the institutional matrix of academic governance—a board of trusties entitled to monitor the rector's performance in strategic execution. Therefore, there are some elementary prerequisites for the strategic accountability created.[5]

The second lesson learned is that to create workable strategic management, factors beyond external enforcement by legal regulations are needed. The internal demands of strategic intent and following through with that intent are required. According to Clark (1983), there are three basic elements in the organization of HE systems: the way tasks are conceived and arranged (the specific division of labor for technologies focused on specific materials and knowledge), culture (beliefs, norms and values, and the symbolic elements of the organization closely interlocked with its structure), and authority (the distribution of legitimate power throughout the system). Therefore, there are two basic possibilities for enhancing internally driven strategic management in HEIs.

One is based on changes in the authority distribution within an HEI in such a way that it creates a center of power not only interested in formulating a strategy on its own but also able to fully execute it. Many changes in HE sectors in the New

[5]However, one could find that these changes are in the vein of entrepreneurial university and abandon Humboldtian ideal—what is controversial per se.

Public Management vein observed worldwide in recent decades seem to follow this direction.

The second option is based on culture, which has a powerful impact on academics ("men of ideas"). The university is a type of organization that falls under the Professional Bureaucracy category and relies, for coordination, on the standardization of skills, training, and indoctrination of its professionals, who, in turn, experience considerable control over their own work (Mintzberg, 1979). These specifics could be attributed to the problem of information asymmetry. Much of the work of academic professionals has traits of an experience goods or even a credence goods. The asymmetrical information embodied in academic work challenges the management of academics. Approaches common in business, such as signalling and screening methods, face important obstacles in HEIs. Thus, putting too much pressure on performance measurement and accountability could have side effects (Pietrzak, 2018). Indeed, according to Mintzberg (1979), real reforms in a Professional Bureaucracy do not emerge from the offices of administrators or governmental bureaucrats looking for bringing academics under control; rather, changes are introduced through processes of change among the academics themselves.

Finally, from a methodological point of view, the implementation of BSC in WULS was largely in line with the books of Kaplan and Norton (1996, 2001, 2004, 2006, 2008) and other prominent authors (Niven, 2002, 2005, 2008; Smith, 2007) but only up to the point of deeper operationalization. Targets were defined not at the beginning of BSC's implementation but a few years later, and not for all objectives. There were no strategic initiatives established with project managers, milestones, and deadlines. Moreover, the strategy did not cascade directly to the lower layers. Thus, the loop of the strategic management system proposed by Kaplan and Norton (2008) was not closed. Of course, one can interpret these problems as related to the lack of prerequisites such as governance and accountability mechanisms.

However, one could expect that these problems have deeper causes. According to Mintzberg (1979), if stakeholders (clients, nonprofessional administrators, members of society, and governmental representatives) of Professional Bureaucracies are dissatisfied with their performance, then they do what seems obvious to them—they attempt to control, supervise more tightly, and standardize processes or outputs. Control and supervision may work in the worst cases of incompetency or unreliability, e.g., a professor who misses too many classes may be disciplined, but professional activity is typically too complex and too vague to be seriously supervised by anyone other than the professionals themselves.

On the other hand, this kind of work would be difficult to standardize in both its processes and outputs. Placing too much emphasis on standardization could easily impede and discourage innovation among professionals/academics and force them to satisfy the relevant standards, rather than serving stakeholders with their creativity. Technocratic controls often cannot distinguish between proper conduct and misbehavior, nor are they able to make an incompetent professional become a competent one. Thus, orders, plans, standards, etc. equally constrain misbehaving academics and dedicated ones, as well as incompetent and competent ones. If professionals lose control over their own work, moreover, they can easily become passive (Mintzberg, 1979).

If very deep changes in Professional Bureaucracy come not from the government intending to bring academics under control, nor from new administrators announcing reforms, can the professionals themselves be changed? Returning to Clark's (1983) building blocks of HE systems (work arrangement, culture, and distribution of power), we should instead focus more on the specificity of academic work and its arrangement. Knowledge is a very special kind of material, around which all academic activity is organized. Thus, instead of attempts to control professionals from the outside (strict plans, targets, and standards), we could pay more attention to changing professionals from within. In other words, instead of forcing academics to follow a strategy by using organizational power, perhaps we could instead focus more on the symbolic side of the university (culture and beliefs).

Therefore, the third and the last lesson that I have personally learned, considering the decade of experience described in the above paragraphs, is that I underestimated the specifics of the university as an organization. It is a common opinion in the literature that BSC must be adapted before implementing it in HEIs. This was also the opinion of our project team, and we did our best to fulfil this requirement. However, we applied the same method used by many others—we rearranged the model by rearranging perspectives and changing the logic of their cause-end-effect interrelations, as well as renaming some of them. This is a common method of adaptation among other public agencies and even NGOs. However, such an adaptation may not be enough. Perhaps it is too superficial? Mintzberg (1979) claims that proper strategic considerations in Professional Bureaucracies should occur at the level of individual professionals, who experience considerable autonomy and often select their own clients and methods of dealing with them. Thus, such professionals could be considered as the ultimate unit of a product–market strategy. Therefore, we should consider rethinking our conception of what a university strategy is and how BSC could be helpful in executing it.

Mintzberg (1987) outlined a strategy in five dimensions, a plan, a ploy, a pattern, a position, and a perspective (5 Ps). The last option appears to be the best way to view strategy for HEIs, where strategy represents a perspective. This raises questions about intentions and actions in a collective context. As the ultimate strategic executor, each academic should pursue his/her own strategy, thus requiring some broader strategic perspectives to fit individual academic intent. From this point of view, the mission, as a common identity, an inspiring vision, and a clear strategy map narrating the desired direction of a whole community is more important than time-scaled targets, performance standards, and detailed initiatives. The interpretation of a strategy map as a form of strategic narration that integrates the academic community seems very promising. After all, according to the Nobel laureate in economics, Robert Shiller (2017), we are ultimately *homo narrans*.

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Chapter 15
E-Learning in Times of Crisis: An Incidental or Facilitative Event?

Nitza Davidovitch and Rivka Wadmany

Abstract As a result of the COVID-19 epidemic that erupted in 2020 the various higher education institutions in Israel, as elsewhere, were compelled to embrace E-Learning at short notice. This was a revolution that appeared with no preparation and that put on the agenda the efficacy of E-Learning from pedagogical aspects and the implications of the lecturer's functions and the act of teaching for the quality of students' learning as well as for the meaning of the learning expanse (campus—home) in teaching and learning processes. The current study examined the opinions of students and lecturers regarding the advantages and disadvantages of E-Learning from various aspects in a systemic, multi-institutional perspective. The study included 2015 students studying at various academic institutions: universities, academic teachers' colleges, academic colleges, and private colleges. The study also included 223 lecturers.

The research findings show that the respondents did not display a high preference for E-Learning: less than half the students and about one-third of the lecturers expressed a preference for E-Learning. Both groups noted the lack of personal, social, and emotional interaction with both students and lecturers as one of the main shortcomings of E-Learning. Most of the students and lecturers did not grasp E-Learning as providing them with better quality teaching and learning. The study illuminates the role of the lecturer in the digital era as a teacher, and particularly—the role of the professional elements in charge of teaching and learning at academic institutions, particularly in the pedagogical aspects. According to student evaluations, the use of technological platforms and tools does not improve teaching, as they are used by the faculty only technically with no matching pedagogy. In order to succeed, E-Learning requires other pedagogical educational

N. Davidovitch (✉)
School of Education, Ariel University, Ariel, Israel
e-mail: d.nitza@ariel.ac.il

R. Wadmany
The Council for Higher Education, Jerusalem, Israel

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approaches aside from copying frontal teaching patterns using the Zoom platform, as well as others: Weber, MS Teams, etc.

In addition, the study indicates the need for perceptual changes, both by the students, who must take responsibility for their learning, and by the lecturers, who must reexamine the teaching and learning processes and adapt their role and areas of responsibility to the new opportunities afforded by the technological tools. The research findings also indicate that effective teaching is teaching that arouses in student's inquisitiveness, motivation, and learning experiences, and note that learning products must be adapted to include essential skills in addition to knowledge. Further, the study illuminates the thorough discussion that must be held by leaders of higher education and of the academic institutions concerning the new effective designation of the campus after the COVID-19 crisis, including distinguishing between the virtual and the realistic in academic teaching and challenges and ways of dealing with the new circumstances.

Keywords E-Learning · COVID-19 · Crisis · Higher education · Technology · Pedagogical aspects · Questionnaire · Regression

15.1 Introduction

For years, many studies have examined the shortcomings and advantages of E-Learning among students (Davidovitch & Yavich, 2015, 2016, 2018). These studies addressed a variety of areas, for instance, the interpersonal interaction between participants in study groups, including the lecturer, students' satisfaction with lecturers' teaching, and learners' achievements (Cohen & Davidovitch, 2020; Wadmany, 2017, 2018).

The COVID-19 crisis (December 2019) compelled all institutions of higher education, in Israel and around the world, lecturers and students, to transition to full online studies, rapidly and with no preparation (Altbach & De Wit, 2020). The second semester (2020) at Israeli universities and colleges opened via E-Learning, learning in a time of global crisis, with the students restricted to their homes (in quarantine) and compelled to complete their academic duties on an online system using computers. The faculty had to undergo an essential change in the teaching techniques they had prepared and aimed for and to transform their way of teaching and learning in order to do their best for their students. These changes, which began with the appearance of COVID-19, may constitute the foundation of a new way of teaching, creative thinking, and planning, for students and lecturers (Davidovitch & Eckhaus, 2020; DePietro, 2020).

Moreover, institutions of higher education invest many resources in developing distance learning courses and are required to enhance lecturers' knowledge and proficiency in the pedagogical dimension, facilitated by technology. Many questions are emerging regarding the learning products of technology-enhanced teaching

(Davidovitch, 2014). Are students ready for the new era in learning? Are lecturers prepared?

Hence, the current study explores the opinions of students and lecturers regarding the advantages and disadvantages of E-Learning from various aspects, in a systemic, multi-institutional perspective. This, with the aim of examining the new effective designation of the academic campus after the COVID-19 crisis. What will be the nature of the academic learning domain in the aftermath of the crisis?

15.2 Literature Review

15.2.1 Information and Communications Technology-based Teaching in Higher Education: For Whom?

In recent years gradually more academic institutions, universities, and colleges (with the exception of the Open University) are endeavoring to integrate E-Learning in teaching at their academic institutions, perceiving it as an attractive, relevant, and marketing oriented way of teaching and learning. Moreover, E-Learning is relevant for students who combine work with studies and therefore require flexible study hours and less demand for physical presence on campus. This is particularly true in the Israeli circumstances, where students only begin their studies after completing military service, i.e., at least three years later than their peers in other countries (Cohen & Davidovitch, 2020).

When wishing to examine whether E-Learning is effective we must examine the study methods rather than the technology used to implement them, because studies indicate that technology does not change the learning rather is only a means (Wadmany, 2017, 2018). In a critical article titled “Media will never influence learning,” Clark (1994) writes that what affects learning is not the technology rather the study method.

Indeed, the findings of a study conducted at the Technion show that students who studied from a distance had more positive attitudes toward asynchronous learning (online contents with pre-recorded lectures) than students who studied face-to-face, because they believed that learning from a distance at their leisure might help advance their learning skills (Barak et al., 2012). Furthermore, students who studied from a distance were also found to express more positive attitudes via their perceived self-efficacy. Namely, in order to succeed in distance learning, students must believe in their ability to manage the academic process, find motivation and cognitive resources, and carry out the necessary operations in order to do well in a course (Barak et al., 2012).

We learn from the research literature that in order for learning to be effective, many students need a supportive human framework and direct contact with the lecturer. Regarding distance learning, researchers note the learning environment as a learner-focused environment when teaching is conveyed directly from the lecturer to the student, versus frontal teaching where the teacher constitutes the major part of the learner's environment. In distance learning the learner is perceived as independent, an active learner with freedom of choice and the liberty to decide about his learning process, one responsible for managing his own study time, with high motivation, a high degree of self-efficacy, one who believes in himself and his abilities, with high self-control and thus capable of functioning effectively and dealing with technological difficulties (Wadmany, 2017, 2018; Wagner & McCombs, 1995).

Despite the above, the research also shows that there are problems in the virtual environment that block learners and pose difficulties (Cohen, 1999; Phelps, 2018). One of the major problems stems from the lack of a social framework in the process of distance learning. Some learners are not inclined to study individually and distance learning with its lack of a social framework might not be to their advantage (Cohen & Davidovitch, 2020). In addition, the existing implications of closing down academic institutions and of the transition to E-Learning make it hard for learners and their families, particularly when belonging to lower socioeconomic groups. For instance, there is a concern of disrupting the learning continuity, separation from one's studies, and the lack of an adequate study infrastructure and space—all these might hamper equal opportunity for learners (Weissblei, 2020).

15.2.2 Features of E-Learning

E-Learning is characterized mainly by learning from home or by learning that does not require physical presence at the academic institution, while using moderated technological means (Nir-Gal, 2002). Academic institutions are aware of the economic and marketing potential of these advanced technologies, where such study methods create a shift in the structure of academic teaching at the institution (Allen & Seaman, 2007; Cohen & Davidovitch, 2020; Nir-Gal, 2002). E-Learning facilitates a learning experience by using computers and the Internet, both at the academic institution and elsewhere.

The interaction in the teaching process is manifested in the learner's ability to react to the study material and to receive feedback from the lecturer or other students, affecting the learning efficacy. The technology itself is mainly infrastructure (Dabbagh & Bannan-Ritland, 2005). The choice of how to utilize it depends on its developers and users. In this way, various models of E-Learning have been formed, beginning from the Moodle system, where a lecturer gives a frontal lecture with no aides, through a frontal lecture accompanied by a presentation, to innovative models that combine a range of content sources and attempt to offer new, collaborative, and less centralist learning methods. All these can be performed in a digital format available on the internet for collaborative viewing or learning (Davidovitch & Eckhaus, 2020; Goldschmidt, 2013).

15.2.3 The Added Value of E-Learning: Indeed?

Some argue for the advantages of E-Learning: E-Learning is considered more economical than frontal learning, more easily available—students can study via any device connected to the internet, anywhere and anytime. The institution does not have to invest funds in teaching staff, libraries, lecturers, operation, and regular maintenance of classrooms and study spaces. Moreover, regular expenses of electricity, water, and Internet are significantly lower when students and lecturers are at home and do not attend the academic institution (Anderson, 2008). Faculty, lecturers, and students save a lot of money on transportation and are spared many expenses. With regard to the contents of the classes, the lecturer does not have to repeat the same class several times for different groups (Allen & Seaman, 2007; Goldschmidt, 2013). Lecturers can record the classes in advance and then share them with different groups of students, not necessarily at the same time (Dabbagh & Bannan-Ritland, 2005).

It is well known that E-Learning enables learning at one's own pace. Students can study the courses anytime and anywhere and move around while studying (Barak et al., 2012). If the classes are recorded and uploaded to the web, students who have a family of their own or who work and are normally overloaded with daily tasks, can study when they have the time. This requires viewing skills, even more so than previously. At present, most students consume contents, "meet" friends, perform purchases—on the Internet (Anderson, 2008; Dabbagh & Bannan-Ritland, 2005). Therefore, in distance learning, when the study contents are prerecorded for the students, the study material should be adapted to each student's level and rate of progress (Cohen & Davidovitch, 2020).

Studies also show that E-Learning enables new ways of teaching (DePietro, 2020) and improves students' achievements and test scores. The advantages of digital teaching include easing the lecturer's workload and the transition from teaching tasks to tasks involving exercises and discussions with learners (similar to the "backward course" model), increasing motivation among students, order and organization in teaching, and self-discipline by students (Dabbagh & Bannan-Ritland, 2005; Miller & Forkosh-Baruch, 2018).

15.2.4 Technology as an Efficient Tool for Developing Learning Skills

Active learning is particularly essential in distance learning. The lecturer is not available to help the student "face to face" and is required to employ a different, digital type of discourse. Students must act independently based on the various information sources available to them (Berger-Tikochinski et al., 2020). Active learning was found to be positively related to the satisfaction of the students who utilize digital learning, and it may also contribute to their success in this form of learning (Shain, cited by Berger-Tikochinski et al., 2020).

Information literacy skills are important skills for students in any learning environment, and particularly for students in a distance learning environment. Students who significantly rely on digital resources in their studies are required to develop more thorough abilities of locating information than students who learn in the traditional method (Berger-Tikochinski et al., 2020). Educators must consider wise use of interactive environments on the web to advance significant learning (Ertmer & Ottenbreit-Leftwich, 2010).

Ashburn and Floden (2006) emphasize in their book "Meaningful learning using technology" that for learner's technology is an intellectual partner that helps them advance their thinking, learning, and comprehension regarding the world we live in. Technology-assisted learning can facilitate meaningful learning if based on learners' involvement in constructing knowledge, discourse in the study group, self-expression, and utilization of reflective thinking. This is done through skills of investigation, design, communication, writing, building models, and visualization. Learning in a hi-tech environment must be based on authentic inquiry procedures, structuring knowledge, and collaborative learning by students.

Mioduser et al. (2010) stress that the process of technology-integrated learning is based on a variety of digital literacies, including multi-channel information processing, navigation of the virtual space, communication, visual literacy, hyper-literacy, personal information management, and coping with complexity. These literacies are part of the toolkit of both lecturer and learners, and their use may promote significant learning. In order to thoughtfully implement these types of literacy, it is important to utilize a pedagogy of self-regulation learning (SRL) that emphasizes organization and regulation of the learning by the learner in cognitive processes, meta-cognitive processes, and motivational processes. The students set themselves goals for learning, supervise and control the learning while controlling thinking processes, motivation, and their behavior. Hence, the challenge encountered by teaching staff is to find the right way to integrate technology and to utilize the possibilities it affords in an online space.

In summary, it is necessary to note the difference between E-Learning in times of emergency and E-Learning in times of routine, which requires replanning courses, including deep pedagogical thinking. Therefore, those who experience distance learning in an emergency are not truly exposed to high-quality distance learning and therefore may form a negative opinion about distance learning.

In times of emergency such as the COVID-19 crisis, which make it necessary to stop activities at educational institutions, the use of digital learning makes it possible for learners to maintain a study continuity and to reduce the disruption of their study routine, while also providing an emotional response and creating a supportive social-educational framework (Altbach & De Wit, 2020). The use of online learning, in the case of synchronous learning, affords students access to the study material in their free time or, when scheduled in advance, makes it possible for them to maintain contact with their peers and with the lecturers, to ask questions, participate in discussions in the online class, and so on (Weissblei, 2020).

15.3 The Challenges of the Transition to E-Learning

E-Learning provides opportunities for changing conceptions regarding teaching and learning and for attention to the following aspects:

1. *Creating a setting with a "flexible" time and place*—Students might turn the digital option into a lack of commitment, into flexibility interpreted as a release from an obligatory learning environment (Benade, 2017).
2. *Managing time and learning*—Students are required to display skills involving time management and personal responsibility for their learning. Studies show that the ability to manage learning and the demands of courses in a flexible environment constitute a key to success in any learning, and particularly digital learning that affords more opportunities in an expanded time and place (Allen & Seaman, 2007; Hershkowitz & Kaberman, 2009).
3. *Change and adjustment*—The transition from traditional learning to digital learning turns learning experiences into something completely different for the students and lecturers. This transition generates resistance to such a change and difficulty handling it. The transition does not let students and lecturers adjust easily to the E-Learning environment and they need time to adapt and to shift to a different type of pedagogy. Previously accustomed to and expecting a "face to face" study experience, a human experience of learning and teaching—they are compelled to be part of a process they did not anticipate. Students and lecturers with a "traditional" spirit find it hard to adjust to the machine. They are required, against their will, to accept the new learning circumstances with an open mind and heart, to understand the advantages of E-Learning, such that a discussion of these advantages with their peers might change this spirit and better prepare students for online classes (Bates & Khasawneh, 2007; Joanna & Jason, 2016; Kovoor, 2020; Palloff & Pratt, 2007).
4. *Lack of digital literacy*—Although most students have experienced in the technological field, they lack digital literacy, in a world flooded with knowledge in English and Hebrew. The ability to judge material, criticize, examine the relevance for a specific topic—all these are manifestations of digital proficiency (Bates & Khasawneh, 2007; Palloff & Pratt, 2007).

   We shall demonstrate reading digital texts—reading academic texts in a digital format is for most learners a complicated and tiring matter as a result of orientation difficulties and the sense of fatigue by those who read a digital text. Consequently, they may attain lower achievements than those who read printed texts (Bates & Khasawneh, 2007).
5. *Operating technology, creating a new study space*—Distance learning poses a challenge regarding providing a response for students who do not have access to the internet or to other means necessary for distance E-Learning (Phelps, 2018; Weissblei, 2020).
6. *Lecturer skills*—Lecturers lack pedagogical skills necessary for efficient and effective use of online technologies (Palloff & Pratt, 2007). A lack of these skills might lead to unwise use of these technologies for learning and teaching and

meaningful use of teaching options in the online expanse (Bates & Khasawneh, 2007).

7. *Equality and quarantine*—One of the major challenges in the context of E-Learning in a time of crisis is equal opportunity for learners. Among the actions taken by different countries in this context are distributing or lending end devices to needy students, offering Internet packages at reduced prices, providing an option of receiving printed study materials, and more. UNESCO too stresses that quarantine and closing schools intensify the existing gaps and inequality in the educational system and that schoolchildren, as well as academic students from disadvantaged populations, are particularly vulnerable to the consequences of the crisis, as in addition to the loss of learning opportunities they are also under increased economic and social pressures (Weissblei, 2020). Moreover, many students describe a sense of loneliness and social disconnection when learning in an online environment. Students emphasize the lack of physical means of reinforcement that usually exist in face-to-face learning (Cohen & Davidovitch, 2020). This sense of loneliness had a negative impact on students' academic achievements (Eshet-Alkalai & Geri, 2007; Hershkowitz & Kaberman, 2009).
8. *Motivation, willpower, and self-demand*—Self-motivation is a vital requirement for learning, both in general and in online learning specifically. Nevertheless, many learners who study online are found to lack motivation (Cohen & Davidovitch, 2020). It is apparent that many students, after registering for distance learning courses, remain behind and do not progress during the course, allowing themselves to lag (Song et al., 2004). Therefore, when planning any course involving distance teaching it is important to provide learners with constant encouragement and reinforcement in order to raise their motivation for this form of learning (Salmon, 2019). Moreover, students must be encouraged to find the motivation to follow the course consistently and to equip themselves well for future challenges. Only a positive attitude and motivation will help them overcome the challenges of E-Learning. Despite the difficulties involved in practicing the transition, students must understand that it is essential in order to reap the benefits of E-Learning in the future (Palloff & Pratt, 2007).

In summary, the COVID-19 crisis is a great opportunity to accelerate pedagogical processes in academia. A real window of opportunity has opened for change and for transitioning from a system based on teaching and imparting information to one based on learning. In fact, this is an opportunity for rapid assimilation of technologies, innovative pedagogy, and advanced management mechanisms (Altbach & De Wit, 2020). The COVID-19 crisis has proven that the academic system in general and the faculty and students in particular have the resilience and ability to function in times of crisis. Distance learning took a quantum leap while teaching, learning, and evaluation took center stage in academic work. In a short span of time the classroom walls came down, digital spheres were established, contents were developed, and collegiality and collaboration among academic institutions intensified. The use of E-Learning accelerated, making room for independence and creativity. These independence and initiatives must be further encouraged and enhanced. At the same time, it was clarified that E-Learning cannot function by copy-pasting frontal learning and requires a different pedagogy. It is necessary to rethink contents, pedagogy, learning methods, as well as of means of evaluation (DePietro, 2020). There is a large discrepancy between the learning skills acquired in the traditional classroom and in the virtual classroom, and this must be compensated for.

Side by side with the difficulties that emerge in the shadow of crisis, distance learning was found to have advantages as well, and the challenges that await us must be further treated. We are at a point in time that constitutes an opening for many studies on the topic of E-Learning and a vehicle for changes and actions in academic instruction. An opportunity has been formed for developing creative learning models. Hence, the current study examines the effect of E-Learning in times of emergency in Israel's system of higher education, including the perception of its advantages and disadvantages by students and lecturers.

15.4 Research Method

This study is a quantitative study based on an attitudes survey conducted among students and lecturers at academic institutions in Israel: universities and colleges. The purpose of the study was to examine the impact of E-Learning in times of emergency in Israel's system of higher education, including its perceived advantages and disadvantages among students and lecturers. The questionnaire presented the respondents with several claims concerning the impact of E-Learning on the quality of learning, to identify its advantages and disadvantages. The respondents were asked to rank their replies on a scale of 1–5 (where 1 means not at all and 5 means very much). The respondents replied, "very much" (5) or "not at all" (1) to several statements related to the different effects of E-Learning on the quality of teaching and learning.

The study was carried out via a wide survey among students at universities and colleges in Israel, of whom 57.7% were students at public colleges, 26.6% at teachers' colleges, 12.8% at universities, and 3% at private colleges.

15.4.1 Research Questions

1. What are the personal, family-occupational, and academic background characteristics of the students?
2. What are the personal, occupational, and academic background characteristics of the lecturers?
3. What is the personal preference of students and lecturers for E-Learning in general and for different types of classes in particular?

4. What is the personal preference of students for E-Learning by an academic institution (teachers' college, university, private college, public college)?
5. What is the personal preference of students for E-Learning by department (social sciences and humanities, exact sciences)?
6. What type of E-Learning do students most prefer (synchronous, videotaped, combined)?
7. What are students versus lecturers' perceptions regarding the advantages and disadvantages of E-Learning?
8. What difficulties arise in E-Learning as perceived by lecturers?

15.4.2 Characteristics of the Sample

The research population included students and lecturers.

15.4.2.1 Student Characteristics

We shall present the personal, family-occupational, and academic characteristics of the 2015 students examined ($N = 2015$). Of all students, 46.8% were male and 53.2% female. In addition, 87.7% were studying for a bachelor's degree, 39.0% were not employed, 67.6% were single, and 31.1% were married. Also, 89.3% were Jewish, 8.4% had a high socioeconomic status, 68.0% a medium status, and 23.6% a low status. Nevertheless, the large majority (90%) noted that they have the necessary resources and tools for E-Learning. Tables 15.1, 15.2, and 15.3 show the background characteristics of the students who participated in the study.

15.4.2.2 Characteristics of the Lecturers

We shall present the personal, family-occupational, and academic background characteristics of the 223 lecturers. These included 51.0% men and 49.0% women. Also, 62.2% had the rank of lecturer, 19.6% teacher, and 18.2% professor. Regarding discipline, 64.7% were teaching at faculties of social sciences and the humanities and 35.3% exact sciences (Table 15.4).

Table 15.1 Personal background characteristics of students in the sample ($N = 2015$)

Age	Range	16–67
	Mean	27.81
	Median	26
	Standard deviation	7.22
Gender N (%)	Male	933 (46.8%)
	Female	1061 (53.2%)
	Total	100.0%
	Jewish	(89.3%)
Religion N (%)	Muslim	126 (6.3%)
	Christian	28 (1.4%)
	Other	60 (3.0%)
	Total	100.0%
Has special needs N (%)	Yes	98 (5.0%)
	No	1878 (95.0%)
	Total	100.0%
Has language difficulties N (%)	Yes	81 (4.1%)
	No	1882 (95.9%)
	Total	100.0%

Table 15.2 Family-occupational background characteristics of students in the sample ($N = 2015$)

Occupational status N (%)	Employee	1116 (56.4%)
	Not working/unemployed	772 (39.0%)
	Self-employed	89 (4.4%)
	Total	100.0%
Marital status N (%)	Single	1354 (67.7%)
	Married	621 (31.1%)
	Divorced	23 (1.2%)
	Widowed	2 (0.1%)
	Total	100.0%
Financial status N (%)	High	166 (8.4%)
	Medium	1347 (68.0%)
	Low	467 (23.6%)
	Total	100.0%
Residential status N (%)	Rental	805 (40.5%)
	Parents' home	703 (35.3%)
	Dorms	132 (6.6%)
	Other	349 (17.5%)
	Total	100.0%

Table 15.3 Academic background characteristics of students in the sample ($N = 2015$)

Studying for degree	Bachelor's	1715 (87.7%)
	Master's	238 (12.2%)
	PhD	3 (0.2%)
	Total	100.0%
Type of academic institution N (%)	University	146 (12.8%)
	Teachers' college	304 (26.6%)
	Public college	660 (57.7%)
	Private college	34 (3.0%)
	Total	100.0%
Discipline N (%)	Social sciences and humanities	1112 (64.5%)
	Exact sciences	611 (35.5%)
	Total	100.0%

Table 15.4 Background characteristics of lecturers in the sample ($N = 223$)

Age	Range	29–83
	Mean	52.30
	Median	51
	Standard deviation	10.66
Gender N (%)	Male	107 (51.0%)
	Female	103 (49.0%)
	Total	100.0%
Academic rank N (%)	Teacher	41 (19.6%)
	Lecturer	130 (62.2%)
	Professor	52 (18.2%)
	Total	100.0%
Type of academic institution N (%)	University	34 (23.1%)
	Teachers' college	43 (29.3%)
	Public college	56 (38.1%)
	Private college	14 (9.5%)
	Total	100.0%
Field of teaching N (%)	Social sciences and humanities	119 (64.7%)
	Exact sciences	65 (35.3%)
	Total	100.0%

15.5 Research Findings

15.5.1 Preferences Regarding E-Learning

15.5.1.1 Level of Preference

Table 15.5 lists the degree of personal preference expressed by students and lecturers for E-Learning.

Table 15.5 Personal preference for E-Learning

	Level of preference[a]				Mean	Standard deviation
	Low preference	Medium preference	High preference	Total		
Students N (%)	623 (31.1%)	461 (23.0%)	918 (45.9%)	100%	3.30	1.14
Lecturers N (%)	57 (25.6%)	87 (39.0%)	79 (35.4%)	100%	3.18	0.96

[a]The variables were aggregated such that values of 1–2.5 were categorized as indicating a low preference for E-Learning, values of 2.51–3.5 a medium preference, and values higher than 3.51 a high preference for E-Learning. All the distributions of the research variables presented below were aggregated in this method

Table 15.6 Mean of personal preference for E-Learning by academic institution

	Mean	SD	*n*
Teachers' college	3.48	1.11	303
University	3.37	1.18	146
Public college	3.36	0.80	34
Academic college	3.09	1.14	658

Both students and lecturers expressed high readiness to study/teach theoretical classes via E-Learning, but their degree of readiness to study practical classes or workshops online was low. The rate of preference for learning theoretical classes online was high (59%) among students and (69%) among lecturers. The degree of readiness to teach theoretical classes online was higher among lecturers than among students ($t = 4.05, p < 0.01$).

The rates of preference for studying an exercise class online were lower than the rates of preference for studying a theoretical class online, 47% among students and 42% among lecturers. No differences were found between lecturers and students in readiness to study an exercise in a theoretical class online ($t = 0.50$, $p =$ NS). The rates of preference for studying a practical class online were very low (18% among students and 14% among lecturers) and on this topic as well no differences were found in the preferences of the two groups ($t = 1.12$, $p =$ NS). Finally, low preference rates were found also for studying workshops online (27% among students and 19% among lecturers). Students displayed a higher preference than lecturers for studying workshops online ($t = 2.49, p < 0.05$).

15.5.1.2 Preference for E-Learning by Features of Students' Studies

Table 15.6 lists the degree of preference for E-Learning by students' type of academic institution.

Significant differences were found in degree of preference by type of institution ($F = 9.17, p < 0.01$).

Table 15.7 presents the mean for degree of preference for E-Learning by features of the students' department (exact sciences versus social sciences and the humanities).

Table 15.7 Mean for degree of personal preference for E-Learning by features of the department

	Mean	SD	n
Social sciences and humanities	3.31	1.15	1108
Exact sciences	3.30	1.14	608

Table 15.8 Type of preferred online class

	Preferred type of online class			
	Synchronous online class	Videotaped lecture	Combination	Total
Students	54.3% ($n = 1053$)	10.5% ($n = 203$)	35.2% ($n = 682$)	100%

No significant differences were found in the preference for E-Learning by this feature ($t = 0.01, p =$ NS).

15.5.1.3 Type of Online Class Preferred by Students

Another aspect of preferences for E-Learning examined in the study is the type of online class preferred by students: synchronous online class, videotaped lecture, or a combination. Table 15.8 lists students' preferences on this issue.

Evidently, slightly more than half the students preferred a synchronous online class and slightly more than one-third preferred a combination of a synchronous online class and videotaped lectures. Only about one-tenth of the students preferred E-Learning solely by online lectures.

15.5.1.4 Perception of E-Learning

Table 15.9 lists students' different perceptions of E-Learning, as evident from their replies.

Evidently, there is a high degree of agreement among students regarding two perceptions of E-Learning that are unrelated to the teaching process itself: a very high proportion of the students are of the opinion that E-Learning saves resources (such as petrol for traveling to school, hours spent in traffic, time waiting between classes at the university), however, a high proportion of the students regret that E-Learning prevents interpersonal interaction with students and lecturers, to which they are accustomed in the regular form of learning at the university.

Students' perceptions of the contribution of E-Learning to improving teaching are usually negative: about 40% of students are of the opinion that E-Learning improves study abilities versus 32% of students who are of the opinion that E-Learning has a negative impact on study abilities. Regarding the dimensions of lecturer availability, order and organization of studies, interest in studies, and clarity of studies—more students were found to hold the opinion that E-Learning is detrimental to the study experience than those who thought that E-Learning helps improve the academic process.

Table 15.9 Perceived E-Learning by students

	Distribution of scores				Mean	SD	Median
	Low	Medium	High	Total			
Saving resources	22.6% (*n* = 437)	12.4% (*n* = 240)	65.0% (*n* = 1259)	100%	3.74	1.37	4.33
Lack of interpersonal interaction	23.5% (*n* = 450)	17.3% (*n* = 332)	59.2% (*n* = 1136)	100%	3.60	1.27	4.00
Improving learning abilities in E-Learning	32.3% (*n* = 647)	28.6% (*n* = 575)	39.2% (*n* = 789)	100%	3.15	1.00	3.16
Lecturer availability	44.2% (*n* = 881)	28.3% (*n* = 563)	27.5% (*n* = 547)	100%	2.84	1.18	2.75
Improving teaching—order and organization	45.8% (*n* = 907)	23.2% (*n* = 460)	30.9% (*n* = 612)	100%	2.76	1.29	2.80
Improving teaching—interest	51.1% (*n* = 1015)	20.6% (*n* = 409)	28.3% (*n* = 563)	100%	2.67	1.27	2.50
Improving teaching—clarity	51.4% (*n* = 1012)	21.4% (*n* = 421)	27.3% (*n* = 537)	100%	2.58	1.29	2.33

Table 15.10 presents lecturers' perceptions of E-Learning.

It is evident from Table 15.10 that lecturers have negative opinions on this type of teaching, even more so than students: Two-thirds of the lecturers were unhappy that E-Learning reduces their interpersonal interactions with the students and among themselves. The proportion of lecturers who missed the social interaction was even higher than the proportion of students with this attitude ($t = 14.68, p < 0.01$).

In addition, only about one-fifth of the lecturers were of the opinion that E-Learning is of a higher quality than regular teaching, and here too it seems that lecturers' perception of E-Learning is more negative than students. Only one-sixth of the lecturers were of the opinion that E-Learning is beneficial for students with regard to students' ability to deal with the studies and with the study material or to benefit from the classes.

15.5.1.5 Difficulties with Implementing E-Learning

Table 15.11 presents the findings of an open question in which students were asked to note the resources they lack in order to implement E-Learning.

The replies given show that 62% of the interviewees who have difficulties implementing E-Learning noted that the difficulty is related to technological infrastructure (lack of a computer, Internet infrastructure, camera, microphone, and so on), 13.7% noted that the difficulty is related to a lack of proper studying conditions (place to study, quiet necessary to study), and 13.2% noted a difficulty with adjusting to E-Learning (lack of concentration, motivation, or time, preference for frontal teaching, lack of technological knowledge necessary for E-Learning). Ten percent of the students noted that they do not have the necessary resources to implement E-Learning.

Analysis of the demographic features of interviewees who noted that they lack resources for online studies indicates the following findings:

- More men than women noted that they lack resources for E-Learning (11.2% vs. 8.4%, respectively; $\chi = 4.48, p < 0.05$).
- Those who noted having difficulties with E-Learning were slightly older than those who did not note such difficulties (mean age of 28.0 vs. 26.2; $t = 10.52, p < 0.01$).
- Those who were not working noted that they lack resources more than those who were employed on a salary basis (12.1% vs. 7.5%, respectively; $\chi = 11.74, p < 0.01$).
- Those who had language difficulties reported much more difficulties with E-Learning than those who had no language difficulties (25.0% vs. 9.1%, respectively; $\chi = 22.72, p < 0.01$).
- Students of exact sciences reported more difficulties than students of social sciences and the humanities (13.1% vs. 8.2%, respectively; $\chi = 10.43, p < 0.01$).

Table 15.10 Perception of E-Learning by lecturers

	Distribution of scores						
	Low	Medium	High	Total	Mean	SD	Median
Lack of interpersonal interaction	13.4% ($n = 29$)	20.7% ($n = 45$)	65.9% ($n = 143$)	100%	4.36	0.63	4.00
Interest, order, organization, and clarity in teaching	42.6% ($n = 92$)	37.5% ($n = 81$)	19.9% ($n = 43$)	100%	2.80	0.89	2.81
Benefit for the students	45.0% ($n = 100$)	39.2% ($n = 87$)	15.8% ($n = 35$)	100%	2.71	0.77	2.63

Table 15.11 Missing resources for E-Learning (among students who noted a lack)[a]

	N	%
Lack of computer	69	36.5%
Lack of internet infrastructure	47	24.9%
Lack of place for studying	21	11.1%
Lack of camera/microphone	15	7.9%
Lack of quiet place for studying	10	5.3%
Lack of concentration/motivation/time	10	5.3%
Prefers frontal teaching	10	5.3%
Lack of printer	8	4.2%
Lack of technological knowledge	5	2.6%
Other	9	4.8%
Did not reply	15	7.9%
Total	189	115.80%

[a]The report included replies noted by at least 5 students. Each student could mark more than one answer, so the percentages do not total one hundred

- No differences were found in the proportion of those who reported that friends are resources for learning between those with versus those without special needs. No differences were found by academic institutions (university vs. college) as well.

15.5.1.6 Factors Affecting Personal Preference for E-Learning Among Students

The variables predicting personal preferences for E-Learning among students were examined by constructing a linear regression model: Model 1, in which the dependent variable is the student's preference for E-Learning and the independent variables are all the other research measures (saving resources, lack of interpersonal interaction, improving learning abilities in E-Learning, lecturer availability, and the three measures of teaching improvement).

The regression model in Model 1 is significant ($F_{(7,1888)} = 1363.2$, $p < 0.001$) and explains 83% of the variance between students in preferences for E-Learning ($r^2 = 0.835$). The regression coefficients are listed in Table 15.12. Although all the independent variables were found to be significant predictors of personal preference for E-Learning among students, the most conspicuous predictor is improving learning abilities in E-Learning. Other variables that are significant predictors of personal preference for E-Learning (although the strength of their prediction is about half that of improving learning abilities) are desire for interpersonal interaction, interest in teaching, and saving resources.

The second model examined is a hierarchic regression model, which in the first stage included background variables of the students (gender, occupational status, studying in a department of exact sciences or social sciences and the humanities,

Table 15.12 Linear regression coefficients for students: Model 1—predicted only by measures of perceived E-Learning

	B	*β*	*t*
Constant	1.52		17.35**
Improving learning abilities in E-Learning	0.48	0.43	19.16**
Lack of interpersonal interaction	−0.20	−0.23	16.15**
Improving teaching—interest	0.19	0.21	8.91**
Saving resources	0.15	0.18	15.15**
Improving teaching—order and organization	0.07	0.08	3.88**
Lecturer availability	−0.07	−0.07	−5.55**
Improving teaching—clarity	−0.04	−0.06	−2.44*

$^{**}p < 0.01$, $^{*}p < 0.05$

Table 15.13 Features of the model among students: Model 2—predicted by background variables and measures of perceived E-Learning

	F	r^2
Sub-model A—Predictors: background variables	111.1*	0.62
Sub-model B—Predictors: background variables and perception of online environment	232.0*	0.85

$^{*}p < 0.01$

special needs, language difficulties, significance of grades for the student and the level of grades attained, difficulties with online learning) and in the second stage also the research measures as in the first model. Table 15.13 presents the features of the regression model in the first and second stages of the overall model.

It is evident that both sub-models are significant. The background variables explain a considerable proportion (62%) of the differences between students in their preference for E-Learning, but the measures of perceived E-Learning also add to the ability to explain the variance in the overall model, which reached 85%.

The following is the key for the dichotomous variables in the tables:

Gender: 0 = female, 1 = male; occupational status: 1 = employee, 2 = other
Special needs: 1 = yes; 0 = no; language difficulties: 1 = yes, 0 = no
Department: 1 = exact sciences; 0 = other; marks: 1 = higher than 80, 0 = lower than 80
Type of institution: 1 = university, 0 = other

Table 15.14 presents the regression coefficients in the first model that includes predictors of preference for E-Learning, which are background variables.

At this stage, 8 background variables were found to explain the preference for E-Learning, but the most conspicuous was the perception of E-Learning on grades: the more important it is for the student to achieve high grades in his or her academic studies, the lower the readiness to study online. Other variables found to predict the preference for E-Learning but their impact on preference is one-fifth or less than that of the grade significance variable are lack of resources for E-Learning, studying in

Table 15.14 Linear regression coefficients for students: Model 2 sub-model A—predicted by background variables

	B	*β*	*t*
Constant	6.03		20.74**
Significance of grades	−0.52	−0.73	−31.55**
Has resources for E-Learning	−0.55	−0.15	−6.66**
Type of department (exact sciences/social)	0.27	0.11	4.54**
Occupational status	0.20	0.09	3.95**
Type of institution (university/college)	−0.14	−0.09	−2.22*
Special needs	−0.21	−0.04	1.86
Age	−0.01	−0.03	−1.56
Personal evaluation by the student	−0.01	−0.01	0.27
Gender	−0.04	−0.02	0.86
Language difficulties	0.15	0.02	1.07
Student's grades	−0.06	−0.02	−1.13

**$p < 0.01$, *$p < 0.05$

a department that belongs to the exact sciences, employee occupational status, and studying in a college.

Table 15.15 presents the regression coefficient in the second model that includes predictors of the preference for E-Learning, which are background variables and measures of perceived E-Learning.

Improving learning abilities via E-Learning is the strongest predictor of preference for E-Learning, as found in Model 1. Other conspicuous variables predicting preference are saving resources, which increases the preference, and desire for interpersonal interaction and high significance of grades for the student, which decrease the preference rates.

15.5.1.7 Factors that Affect One's Personal Preference for E-Learning among Lecturers

As among students, two models were calculated to try and predict faculty members' personal preference for E-Learning. The first model included only variables related to teaching per se (namely, the perceived benefits of E-Learning for students; interest, order, organization, and clarity of teaching; and perceived lack of personal interaction). The following is the first linear regression model (Table 15.16).

The first regression model is significant ($F(3,212) = 111.05$, $p < 0.01$) and explains 61% of the differences between faculty members in the preference for E-Learning ($r^2 = 0.611$). The findings indicate that all three variables related to perceived E-Learning are significant predictors of the preference for E-Learning, but the variable of perceived interest, order, organization, and clarity in teaching—has greater prediction strength than the two other variables.

Table 15.15 Linear regression coefficients for students: Model 2 sub-model B (full model)—predicted by background variables and measures of perceived E-Learning

	B	*β*	*t*
Constant	2.75		11.67**
Improving study abilities in E-Learning	0.46	0.41	11.46**
Saving resources	0.15	0.19	10.30**
Lack of interpersonal interaction	−0.18	−0.19	−8.79**
Significance of grades	−0.10	−0.15	−6.17**
Improving teaching—interest	0.08	0.09	2.45*
Improving teaching—order and organization	0.07	0.09	2.63**
Has resources for E-Learning	−0.27	−0.07	−5.05**
Type of institution (university/college)	−0.08	−0.06	−2.09*
Improving teaching—clarity	−0.05	−0.06	−1.84
Type of department (exact sciences/social)	0.12	0.05	3.07**
Lecturer availability	−0.04	−0.04	−1.86
Age	−0.01	−0.03	−2.21*
Occupational status	0.05	0.02	1.46
Special needs	−0.14	−0.02	−1.98*
Language difficulties	−0.04	−0.01	−0.46
Student's grades	−0.02	−0.01	−0.57
Personal evaluation of the student	−0.01	−0.01	−0.66
Gender	0.01	0.00	0.28

**$p < 0.01$, *$p < 0.05$

Table 15.16 Linear regression coefficients among lecturers: Model 1—predicted only by measures of perceived E-Learning

	B	*β*	*t*
Constant	2.14		5.94*
Interest, order, organization, and clarity in teaching	0.39	0.37	4.99*
Lack of interpersonal interaction	−0.24	−0.25	−4.59*
Benefits for students	0.32	0.25	3.18*

*$p < 0.01$

The second regression model calculated includes in sub-model A an examination of the effect of background variables on the preference for E-Learning (including the significance of teacher evaluations, present score in teacher evaluations, academic institution—university versus college, teaching exact sciences or social sciences and the humanities, self-evaluation as a lecturer, age, gender, academic rank). Sub-model B includes all the above variables as well as the measures of perceived E-Learning.

Table 15.17 presents the characteristics of the regression model in the first and second stages of the overall model.

It is evident that both sub-models are significant, and that the sub-model that includes only background variables explains about one-third of the differences

Table 15.17 Characteristics of the model among lecturers: Model 2—predicted by background variables and measures of perceived E-Learning

	F	r^2
Sub-model A—Predictors: Background variables	6.10*	0.32
Sub-model B—Predictors: Background variables and perception of the online environment	18.18*	0.67

*$p < 0.01$

Table 15.18 Linear regression coefficients among lecturers: Model 2 sub-model A—predicted by background variables

	B	β	t
Constant	5.74		7.45*
Significance of evaluations received by the faculty member	−0.38	−0.53	−6.52*
Age	−0.01	−0.13	−1.53
Gender	−0.22	−0.12	−1.35
Mean teacher evaluations of the faculty member	−0.20	−0.10	−1.06
Self-evaluation as a lecturer	−0.09	−0.06	−0.65
Academic rank	0.17	0.05	0.64
Teaches in department	−0.10	−0.05	−0.61
Academic institution	0.10	0.04	0.53

*$p < 0.01$

among faculty members in the preference for E-Learning, while the full model explains about two-thirds of the differences in preference (Table 15.18).

The findings indicate that the only background variable that explains the preference for E-Learning among lecturers is their concern that their teacher evaluation scores will drop following the transition to E-Learning.

Table 15.19 presents the regression coefficients for the entire second model, which includes predictors of preference for E-Learning in the form of background variables and measures of perceived E-Learning. The perceived lack of interpersonal interaction is the most influential variable (negatively) on lecturers' degree of preference for E-Learning, and two variables related to learning highly affect readiness: benefits of E-Learning for students, and interest, order, organization, and clarity of teaching.

Two background variables that have less of an effect on preference, but their impact is significant are also worthy of note: age (the preference for E-Learning drops with the lecturer's age) and the concern that a transition to E-Learning will negatively affect the evaluations received by the faculty member.

Table 15.19 Linear regression coefficients among lecturers: Model 2 sub-model B (full model)—predicted by background variables and measures of perceived E-Learning

	B	*β*	*t*
Constant	4.33		6.28**
Lack of interpersonal interaction	−0.28	−0.30	−4.12**
Benefits for students	0.33	0.27	2.50*
Interest, order, organization, and clarity in teaching	0.27	0.26	2.47*
Age	−0.01	−0.17	−2.83**
Significance of the evaluations received by the faculty member	−0.11	−0.15	−2.26*
Self-evaluation as a lecturer	−0.14	−0.09	−1.34
Gender	−0.16	−0.08	−1.38
Academic institution	0.11	0.05	0.79
Department	0.06	0.03	0.53
Mean evaluation score of the faculty member	0.05	0.02	0.38
Academic rank	−0.03	−0.01	−0.19

**$p < 0.01$, *$p < 0.05$

15.6 Summary of the Findings and Discussion

The current study examined the opinions of students and lecturers regarding the advantages and disadvantages of E-Learning from various aspects, in a systemic multi-institutional perspective. The study included students at various academic institutions: universities, teachers' colleges, public colleges, and private colleges.

The research findings indicate that *the degree of preference for E-Learning is not high*: Less than half the students and about one-third of the lecturers expressed a preference for studying in this format. *Both groups noted the lack of personal interaction with students and lecturers* as one of the main shortcomings of E-Learning. Another perceived shortcoming of E-Learning that emerged in both groups is the concern of harm to students' grade average or to lecturers' mean evaluations by students following the transition to E-Learning.

Saving resources is one of the strengths of E-Learning as perceived by the students. Nevertheless, most do not perceive E-Learning as advantageous for them with regard to the quality of learning per se. Notably, improving the ability to study online is the measure that most influenced students' preference for E-Learning, but only 39% of the students were of the opinion that E-Learning indeed offers them such an advantage.

The perceived benefit of E-Learning for students and the degree of interest, order, organization, and clarity in teaching are elements that have considerable influence on the preference for E-Learning among lecturers, but less than half the lecturers were of the opinion that E-Learning encompasses these features. Notably, older lecturers showed less preference for E-Learning versus younger lecturers, perhaps because they feel stronger adjustment difficulties to teaching in this method.

Both the students and the lecturers were of the opinion that E-Learning is not equally suited for all types of classes. Both groups mostly think that it is possible to teach a theory class via E-Learning, but few think that a workshop or practical class can be taught in this way.

Students prefer E-Learning via a synchronous online class over E-Learning via videotaped lectures, and some think that the best way to learn online is by a combination of these methods.

About one-tenth of the students reported that there is a problem that prevents them from studying online. The main difficulty reported by the students was a lack of technology that facilitates implementation of E-Learning (computer, microphone, camera, etc.), and other difficulties were a lack of proper study conditions and a difficulty with adjustment to online studies. The large majority (90%) noted that they have the necessary resources and tools for E-Learning.

According to students' evaluations, use of technology was not found to be thoughtful or to affect the quality of teaching. It appears that faculty members use technology technically more than pedagogically. A possible explanation for the criticism voiced by students is the considerable difference between emergency E-Learning and routine E-Learning, which requires replanning courses, including extensive pedagogical thinking. Therefore, those who experience distance learning in times of emergency are not truly exposed to high-quality distance learning and thus may formulate a negative opinion about distance learning.

In times of emergency, E-Learning constitutes a solution to the option of closing down the entire school system (Altbach & De Wit, 2020). The measures of teaching quality and success in times of emergency and in times of routine differ. In times of emergency, there is less of a demand that lecturers maintain the study pace, in the understanding that these times will end shortly and it will be possible to close the gaps, which does not happen in times of routine. In this case as well the students demanded more professionalism of lecturers in E-Learning and preparation of high standard study material, as well as advanced interactions facilitated by online systems, such as the interaction between students and lecturers, discussions, group work in private rooms, collaborative environments, and more.

As stated, the students and the lecturers noted the lack of personal, social, and emotional interaction (SEL—social and emotional learning) with students and lecturers as one of the main shortcomings of E-Learning/teaching. These findings correspond with Salmon's (2019) model, which claims that at the beginning of every online course, after overcoming the technical difficulties, it is necessary to develop socialization among the learners, encourage them to text each other and establish their identity on the Internet. This stage is essential for establishing efficient teaching/learning further on.

The study illuminates the role of the lecturer in the digital era, in teaching and particularly—the role of the professional elements responsible for teaching and learning in academic institutions, with its pedagogical aspects. The new pedagogic world must set itself renewed goals and reformulate the image of the new teacher, i.e., the digital pedagogue. The digital pedagogue must understand the new opportunities afforded by the technological world to create a learning environment that will deal with more plentiful, varied, and value-laden tasks than ever before (Benade, 2017).

Most of the institutional studies on ICT (Information and Communications Technology) focus on the number of courses taught, the number of students participating, and the success of E-Learning. They scarcely refer to how ICT-based teaching can be utilized to upgrade teaching and learning and how online aspects can be used to improve various pedagogical issues such as interaction between the faculty and the students or improving course contents. In the recognition that the COVID-19 era facilitates thinking that encompasses a paradigmatic change, there is a need for discovery and assimilation of new pedagogies that are uniquely suited to the new technologies found. In order to improve lecturers' teaching, it is necessary to boost the pedagogical aspects of the new technological tools. A program should be offered that assimilates the new tools as an inseparable part of the practice of teaching rather than as an external aide to the teaching and learning process. We can assume that the big challenge of online learning is the day after the crisis. Is there a way back?

It will be interesting to repeat the study a year after the crisis and compare the results.

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Chapter 16
The Relative Efficiencies of Higher Education in OECD Countries

Zilla Sinuany-Stern and Arthur Hirsh

Abstract Studies of productivity of systems of Higher Education (HE) on the national level are of interest for two main reasons: education is an important factor for productivity growth for the macro-economy, and the efficiency of spending public resources on HE is of key interest in the context of accountability specifically relative efficiency compared with other developed countries. The objective of this study is to evaluate the relative efficiency of HE in OECD countries from the public viewpoint; how well OECD countries utilize their public resources to achieve their outputs relative to each other. For this study, two inputs are chosen reflecting the public investment in HE. Six outputs are chosen reflecting the main outcomes of HE in terms of: accessibility of tertiary education, employment level, earnings level relative to secondary education, net financial returns from HE, internal rate of return, and research articles level. The data is taken, mostly, from the OECD report on education in 2019. Out of 37 OECD countries 29 are considered in this study. Due to missing data 8 countries are not included. The stress on efficiency from the public viewpoint is a strength of this study in relation to previous OECD efficiency studies. The original Data Envelopment Analyses (DEA) basic models are, which provide dichotomy of the countries into two groups: efficient and inefficient. Moreover, several efficiency rank-scaling methods based on DEA, and several multivariate statistic methods are utilized here. The use of a variety of efficiency rank-scaling methods, while choosing the robust one, is another strength of this research. The results indicate that the robust method is *cross efficiency*, as it is significantly correlated with each of the other efficiency methods, and it has the highest average correlation with other efficient methods. From the 29 studied OECD countries, the USA is found to be the most efficient in HE. However, when we use only the first

Z. Sinuany-Stern (✉)
Department of Industrial Engineering and Management, Ben Gurion University of the Negev, Beer Sheva, Israel
e-mail: zilla@bgu.ac.il

A. Hirsh
Webster Vienna Private University, Vienna, Austria

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input versus the six above outputs, Italy became the most efficient country. The USA is ranked third in this case, while Italy is ranked fourth in the original case.

Keywords Efficiency · OECD · Higher education · Data envelopment analysis · Multivariate statistics · Ranking · Rank-scaling

16.1 Introduction

Since the establishment of the world's first university in the eleventh century, universities have traditionally functioned as ivory towers, often tied with religion, permitting entry to a chosen few. Over centuries, universities retained their elitist status and helped perpetuate social inequalities. After 900 years, this situation, in which an "elite" has hegemony over higher education (HE) came to an end. The end of WWII marks the transition of HE Institutions (HEIs) from elitist to democratic and open in nature. In most Western countries, the accelerated pace of this transformation in the twentieth century led to the massification of academic studies with up to 200 million HE students in 22,000 HEIs institutions by the end of the century (Altbach et al., 2017). In the 1950s, undergraduate students accounted for a mere 3%–5% of their relevant age group (cohorts) in Europe. At the end of the century, these figures ranged from 36% to 53%. Today, in most European countries and the USA, over 60% of cohorts are students in academic institutions (Davidovitch et al., 2012; Lindberg, 2007). In the modern world, universities have two main purposes: to equip students with advanced skills useful in the workplace, and to further human knowledge and understanding of the world. Over the years, the accountability of higher education, and its efficiency have become important issues for public constituencies of HE.

The Organization for Economic Co-operation and Development (OECD) is an international organization of those developed countries that accept the principles of representative democracy and a free market economy. The objective of this study is to evaluate the relative efficiency of HE in OECD countries from a public viewpoint. How well do OECD countries utilize their public resources to achieve their outputs relative to each other country?

Studies of productivity of systems of HE are of interest for two main reasons: education is an important factor for productivity growth for the macro-economy, and the effectiveness of spending the resources is of key interest in the context of accountability (specifically relative efficiency, and benchmark analysis). As shown in Table 16.1 (output Y5) the rate of return on HE public investment among the 29 OECD countries included in this study ranges from 3.1% to 14.3%. Three countries have a rate less than 5%, and eight countries have a rate more than 10%.

There are additional inputs and outputs to be considered in measuring the efficiency of a complex system such as HE. Thus, the basic approach taken here to measure the relative efficiency of decision-making units (DMUs—countries in this case) is data envelopment analysis (DEA), as it can handle multiple inputs

Table 16.1 OECD countries input and output data

	Inputs		Outputs					
Country	X1	X2	Y1	Y2	Y3	Y4	Y5	Y6
Australia	3.626	39.523	45.727	84	131	117,686	0.121	914
Austria	3.555	93.575	32.711	86	147	149,454	0.060	620
Belgium	2.747	82.357	40.638	86	130	207,637	0.111	748
Canada	3.831	53.263	57.888	83	146	70,747	0.070	1102
Chile	5.358	35.842	25.168	84	238	30,983	0.099	349
Czech Republic	1.782	72.506	24.262	87	169	66,202	0.064	427
Denmark	3.708	89.793	38.055	88	128	67,739	0.039	705
Finland	3.274	92.479	45.188	87	140	79,832	0.054	609
France	2.161	77.130	36.897	85	157	103,930	0.069	1094
Germany	2.843	83.013	29.065	89	169	177,514	0.076	1203
Hungary	1.619	62.806	25.101	86	179	105,700	0.092	419
Ireland	2.626	71.699	46.935	85	174	247,211	0.143	488
Israel	2.297	55.956	50.916	87	156	104,724	0.122	665
Italy	1.493	60.971	19.324	81	139	127,733	0.078	953
Korea	2.912	37.577	49.008	78	141	25,636	0.056	624
Latvia	2.047	65.301	33.939	89	146	52,052	0.090	151
Luxembourg	1.136	91.859	43.887	86	148	288,310	0.070	173
Netherlands	4.014	67.485	38.344	90	150	284,446	0.105	957
New Zealand	3.691	50.597	39.293	88	133	64,265	0.074	495
Norway	4.199	93.060	43.576	89	126	48,696	0.034	580
Poland	2.578	78.690	30.920	89	156	73,547	0.074	519
Portugal	1.811	61.390	24.950	88	169	127,847	0.094	457
Slovak Republic	2.005	69.502	24.583	83	163	51,472	0.058	263
Slovenia	2.092	81.623	32.455	89	164.4	146,528	0.084	278
Spain	2.173	65.585	37.253	82	157	61,566	0.065	830
Switzerland	3.885	84.240	43.744	89	153	32,517	0.031	919
Turkey	4.634	73.831	20.780	74	164	123,837	0.115	402
UK	3.269	28.260	45.782	86	142	96,621	0.110	1373
USA	3.086	34.571	47.431	82	172	199,758	0.113	2222

and multiple outputs, with various types of measurement units, when their weights (prices) are unknown. DEA provides dichotomy of the countries into two groups: efficient and inefficient (Banker et al., 1984; Charnes et al., 1978). Moreover, several efficiency rank-scaling methods based on DEA, and several multivariate statistic methods were utilized here (Adler et al., 2002). At the first stage, all the efficiency rank-scaling methods were screened for feasibility in our case study. At a second stage, from the set of feasible efficiency rank-scaling methods, the robust method is found and selected to represent the final robust efficiency scale-rank of OECD countries based on the maximal average correlation of each efficiency method with the other methods (based on Sinuany-Stern & Friedman, 2021).

For this study, two inputs are chosen reflecting the public investment in HE: as a percent of the total government budget, and as a percent of the HEIs total budget. Six outputs are chosen reflecting the main outcomes of HE from public perspective in terms of: accessibility of tertiary education, employment level, earnings level relative to secondary education, net financial returns, internal rate of return, and research articles' level. Out of 37 OECD countries 29 were considered in this study. Due to missing data 8 countries are not included.

There are various applications of DEA to measure the efficiency of OECD countries (e.g., Agasisti, 2011; Aristovnik & Obadic, 2011; Saljoughian et al., 2013). However, as shown in Sect. 16.2.2, each application was limited to a specific DEA version, concentrating on DEA versions which provide a mere dichotomy of the countries into efficient and inefficient—not a full rank scale. None of them deals with a robust solution, and leaves the reader perplexed as to why one method is used and not another. Moreover, some articles concentrate on specific aspects of HE system: research or teaching. While our study considers a variety of multivariate statistical methods and DEA versions dichotomy and full-scale ranks of OECD countries, pointing at the robust solution. Furthermore, both *education* and *research* aspects of HE in OECD countries are considered.

Section 16.2 discusses the variables affecting HE systems efficiency; inputs/outputs chosen by previous studies to measure OECD countries' HE efficiency; and the methodologies they used versus the methodology used in this study. Section 16.3 lays out the inputs and outputs chosen for our OECD study considering Sect. 16.2. Section 16.4 presents the results of two basic DEA models for grouping the countries into two groups efficient and inefficient. CRS (constant return version) is presented showing the weights of inputs and outputs for each country, the improvements each country needs for each output, and some benchmark analysis. Also, VRS (variable returns to scale) efficient and inefficient groups are presented. Following are the results of several full rank-scaling methods DEA based, followed by multivariate statistical efficiencies in the DEA context. Section 16.5 deals with another version of the data, where only 1 input and the six outputs are used. Section 16.6 selects the robust efficiency method. Section 16.7 provides other external factors that may be correlated with the efficiency rank-scale. Section 16.8 highlights the risks of massification in HE, which is the implication of the two first outputs inefficient countries tend to give high weights for (percent of adults attained HE, and percent of employed adults with HE), and its possible ramification, mainly on reducing the economic value of HE. Finally, summary and conclusions are given.

16.2 Variables Affecting National HE Systems

Modern society has developed new expectations of HEIs and academic faculty responsibility: expectations of involvement in social issues and relevant research and studies; expectations of a system that seeks to satisfy national needs; and expectations of professional training to help national advancement—providing necessary professional, technological, and intellectual foundations for promoting efficiency, economy, and administrative capabilities.

16.2.1 The Economic Gains

The economic returns for HE graduates are the highest in the entire educational system (including elementary and secondary education). According to Altbach et al. (2017), today there are around 200 million HE students in the world (it was 89 million in 1998). This is critical because, according to a World Bank Group (WBG) report, a student with a HE degree may earn more than twice as much as a student with only a high school diploma. As expected, there exist differences in the value of HE by country (ibid). Much of this can be understood through each country-specific demand and supply factors.

The Financial Times rankings give overriding importance to graduate's salary criterion (40%) [https://www.universityrankings.ch/methodology/financial_times_rankings, accessed on Feb 27, 2019].

Within the same country, there may be differences among HEIs regarding economic returns on investment. For example, comparing two specific universities in the USA: Stanford graduates—with an average 4-year cost of HE $224,500 and a graduation rate of 96%—expect $809,700 Return on Investment (ROI). Thus, the ratio between returns and investment is 3.6. However, Georgia Tech graduates—with a 4-year cost of $86,700 and graduation rate of 82%—expect ROI of $796,300. Thus, the ratio between the returns and the investment is 9.1. The difference between 3.6 and 9.1 between the two universities' ratios is tremendous! (data source, https://ourworldindata.org/returns-to-education, accessed on Feb. 25, 2019).

16.2.2 Inputs and Output Chosen by Other OECD Efficiency Studies

Agasisti (2011) used DEA (CRS and VRS) to measure HE efficiency on the national level among OECD countries (18 countries) using the following inputs and outputs (OECD in a Glance 2002–2006). They used the following input and output variables.

Inputs:

- Accessibility of the system, which could be measured by means of entry rates.
- The availability of financial resources (private and public investments, in absolute terms and as a proportion of GDP).
- Human resources (number and quality of students and teachers).

Outputs:

- Proportion of population that has attained tertiary education, measured in terms of graduation rates and percentage of educated population.
- Employability of graduates, which also proxies the private returns of HE.
- Attractiveness of the systems, measured through the flows of students from one country to another.

Agasisti (2011) did not use any research outputs.

Aristovnik and Obadic (2011) used two outputs to utilize DEA efficiency of EU and OECD countries (37 in total). DEA technical efficiency was used (VRS). The data was an average over the years 1999–2007. The highlight of the paper is a comparison of Croatia and Slovenia efficiency in relation to the other countries using 3 combinations of the following inputs and outputs.

The inputs were:

- Expenditure per student, tertiary (% of GDP per capita)
- School enrollment, tertiary (% gross)

The outputs were:

- School enrollment, tertiary (% gross)
- Labor force with a tertiary education (% of total)
- Unemployed with a tertiary education (% of total unemployment).

They did not use any research outputs (ibid).

Saljoughian et al. (2013) used science and technology indicators of 28 OECD countries of 2009 data (from World Bank) applying DEA (VRS and Super Efficiency). They rank the countries based on the DEA efficiency results (Super Efficiency), though the weights of inputs and outputs vary from country to country.

The inputs are:

- Research and development expenditure
- Researchers in R&D

The outputs are:

- High-tech exports (current US$)
- Patent applications, residents
- Scientific and technical journal articles
- Trademark applications, direct resident

They used only research inputs and outputs, but they did not use any enrollment data (ibid).

The following references use DEA for evaluating HE in some aspects of OECD countries or subgroup, thus we did not list their inputs/outputs. For example, Ceccobelli et al. (2012) used DEA (Bootstrap) for the evaluation of 14 OECD countries studying the impact of their Information Communication Technology (ICT) inputs on their labor productivity growth during 1995–2005. Wolszczak-Derlacz and Parteka (2011) used DEA (VRS) bootstrap approach, on 259 HEIs from

7 European countries. At a second stage, the efficiency was regressed as a function of explanatory variables. However, there was no analysis by country. Similarly, Veiderpass and McKelvey (2016) evaluated DEA (VRS) efficiency of 944 HEIs in 17 European countries, by institution, using 11 inputs (expenditures and various types of staff), and 5 outputs (headcounts of graduates at different levels). They calculate the average efficiency of every country. Afonso and Kazemi (2017) used DEA (CRS and VRS) for evaluating the efficiency of 20 OECD countries using 9 indicators—education is only one of the indicators.

16.2.3 Methodology—Robust Efficiency of Rank Scales in DEA Context

Our study utilizes the robust efficiency approach where several efficiency rank-scaling methods are used and the best, *robust*, method is verified (Sinuany-Stern & Friedman, 2021). Several DEA-based methodologies and the statistical multivariate efficiency methods are used here for measuring countries efficiencies also taken from Sinuany-Stern and Friedman (2021) and Adler et al. (2002). Thus, they will not be detailed mathematically, but rather intuitively in the context of efficient countries in HE.

The potential of deriving rank-scaling efficiencies based on Super Efficiency (SE) and Cross Efficiency (CE) based on CRS and VRS are presented.

The multivariate statistical methods (in the context of DEA) considered here are Discriminant analysis efficiency (Disc), Canonical Correlation Analysis (CCA) efficiency, and multiple regression efficiency (REG).

16.2.3.1 Constant Returns to Scale Efficiency and Inefficiency: Dichotomy

CRS assumes *Constant Return to Scale.* CRS is the original version of DEA efficiency (Charnes et al., 1978). CRS efficiency is defined as the ratio between the weighted sum of the output and the weighted sum of the inputs, where the weights are unknown (or not agreed upon). In our study, CRS finds for each OECD country the ideal weights of CRS efficiency ratio, subject to positive efficiency ratio of all OECD countries bounded by 1. A country is CRS efficient if its CRS efficiency is 1, while a country is inefficient if its CRS efficiency is less than 1. The advantage of DEA is the ability to reformulate each of its optimization problems (one for each OECD country in our case) into linear programming formulations, which its dual solution provides information on the improvements each country needs to do (the slacks of the dual problem). DEA also provides benchmark analyses pointing at efficient countries that caused an inefficient country not to achieve the maximal CRS efficiency of 1 (countries whose dual variable was positive in the solution of the inefficient country). Consequently, the weights of inputs and outputs vary greatly from one country to another; though all weights are constrained to be non-negative. Due to the variability of the weights from one country to another, CRS efficiencies cannot be comparable to each other and cannot be used for rank-scaling. Nevertheless, CRS efficiencies provide dichotomy of the countries into two groups:

1. CRS efficient (when CRS efficiency = 1 consisting the efficient frontier)
2. CRS inefficient (when CRS efficiency < 1)

16.2.3.2 Variable Returns to Scale Efficiency and Inefficiency: Dichotomy

VRS assumes *Variable Returns to Scale* (Banker et al., 1984). VRS is very similar to CRS only a constant is added to the output or input (depends on the orientation of the application), while for CRS the constant is defined as zero. Again, VRS divides the countries into two groups: efficient (VRS efficiency = 1) and inefficient (efficiency < 1). Any country which is CRS efficient, will always be VRS efficient. VRS usually will add efficient countries since it allows both: constant returns to scale and variable returns to scale. Obviously, with more efficient countries more countries will not need improvements. Weights of inputs and outputs of VRS will differ in relation to CRS. Also, benchmark analysis will differ as the number of inefficient countries decrease for VRS in relation to CRS.

16.2.3.3 Super Efficiency Based on CRS and Cross Efficiency Rank-scaling Based on CRS Method

SE-CRS, *Super Efficiency rank scale* is based on CRS efficiency method, which allows for each country's CRS to run an efficiency value more than 1 by allowing its objective function to be unconstrained by the value1 (Andersen & Petersen, 1993). Therefore, any efficient CRS country may get an efficiency value of more than 1. Thus, a full rank-scale occurs also for the efficient countries.

CE-CRS, *Cross Efficiency rank-scale* is based on CRS efficiency. CE-CRS is derived directly from the original weights of CRS, where each country is evaluated by the weights across all the other countries. The resulting average over all cross efficiencies is the specific country's CE-CRS *efficiency rank-scale* (Sexton et al., 1986).

16.2.3.4 SE-VRS and CE-VRS Efficiency Based on VRS Rank-scaling Method

SE-VRS Super Efficiency VRS *efficiency rank-scale,* and CE-VRS Cross Efficiency VRS *efficiency rank-scale,* are derived from VRS efficiency in procedures parallel to SE-CRS and CE-CRS. It is not always the case that SE-VRS, or CE-VRS is feasible since a constant value is involved in constructing the efficiencies which can be negative or positive in calculating SE-VRS or CE-VRS. While SE-CRS and CE-CRS are always feasible since the constant of CRS is defined as zero.

16.2.3.5 Disc/CRS and Disc/VRS Efficiency Rank-scaling Methods

Disc-CRS is *Discriminant analysis* based on the *CRS* dichotomy, into efficient and inefficient groups. The discriminant function is a linear combination of the inputs and outputs with common weights, each country gets a discriminating value. Higher discriminating value indicates a higher efficiency value. For feasibility, the coefficients of Disc analysis must be negative for the inputs and positive for the outputs.

Disc-VRS is *Discriminant analysis* based on the *VRS* dichotomy into efficient and inefficient countries, the rest of the procedure is like Disc-CRS.

16.2.3.6 Canonical Correlation Efficiency Rank-scaling Method

CCA is *Canonical Correlation* efficiency rank-scale in the DEA context in general—only in using multiple inputs and multiple outputs (Adler et al., 2002). The CCA is, somewhat, a generalization of regression analysis, finding common weights for a linear combination of the multiple outputs as a linear combination of the inputs. The objective of CCA is to maximize the correlation between the two linear combinations. CCA efficiency is calculated as the ratio between the weighted outputs and the weighted inputs. In our context of inputs and outputs of HE in OECD countries, we require that a feasible CCA model must have positive weights, since each output must contribute positively to the overall output, and every input must contribute positively to the overall input in increasing the overall output. If any of the coefficients are negative, then CCA is not feasible.

16.2.3.7 Regression Efficiency Rank-scale

REG is *regression analysis* rank-scale efficiency. REG is applicable only for one input versus multiple outputs or one output versus multiple inputs. The rank-scale is derived from the error terms of the regression for each country. For one input versus multiple outputs, the larger is the error the smaller is the efficiency—positive error means that the actual input is larger than expected (above the regression line); thus, inefficiency and vice versa. Similarly, to CCA, also for REG, the regression coefficients must be positive for feasibility of the rank-scale.

16.2.3.8 Robust Efficiency

At the first stage, all these considered methods were screened for feasibility in our case study. At a second stage from the set of feasible efficiency rank-scaling methods, of the first stage, the robust method is found and selected to represent the final robust efficiency scale-rank of OECD countries, based on the maximal average correlation of each efficiency method with the other methods (Sinuany-Stern & Friedman, 2021).

The next section presents the inputs and outputs chosen for measuring the relative efficiency of OECD countries from the public view including educational outputs and research output.

16.3 The Data on HE Inputs and Outputs of OECD Countries

The objective of this study is to evaluate the efficiency of HE in OECD countries from a public viewpoint in 2019. How well OECD countries utilize their public resources to achieve their outputs relative to each other country. The choice of inputs and outputs is very important. Moreover, the number of variables is limited by the number of observations (Edvardsen et al., 2017). Taking all these into account and considering the inputs and outputs in the literature as shown above, for this study two inputs were chosen reflecting the public investment in HE (see sources in Appendix 1). Six outputs were chosen reflecting the main outcomes of HE in terms of accessibility of HE, employment level, earnings level relative to secondary education, net financial returns, internal rate of return, and research articles level. The variables chosen, reflect the efficiency of public investment in HE. The exact definitions of the inputs and outputs are as follows.

Two inputs are used:

X1—Percentage of Government expenditure allocated for HE.
X2—Percentage of public sources from total HE expenditure.

Six outputs are used:

Y1—Percentage of adults with a HE (any level of HE) the highest level attained.
Y2—Percentage of employed 25–64 year old among all 25–64 year old who attained HE (all levels of HE).
Y3—Relative earning of workers who attained HE relative to upper secondary education (= 100).
Y4—Net financial returns of a person attaining HE as compared with a person attaining upper secondary education, in equivalent USD converted using PPPs for GDP (future values are discounted at a rate of 2%).
Y5—Internal rate of return (of Y4).

Y6—h index: countries number of articles (h) that have received at least h citations—a measure which encompasses quality and quantity simultaneously.

From the public viewpoint, the two inputs reflect the public expenditures in HE as a percentage of total public expenditures (X1), and from the point of view of the HE system—what percentage of their expenditures comes from the public sector (X2). Other expenditures of HE are imbedded in the net public financial returns of a person attaining HE (Y4); namely, Y4 is the difference between the total benefit and the total expenditure. Since the number of OEDC countries with full data is limited, the number of variables (2 + 6 = 8) is quite large as is. The six outputs selected to cover a large array of outputs from the public viewpoint: percentage of adults with HE (Y1) reflecting HE accessibility, employment rate (Y2), graduates' earnings (Y3), net financial returns (Y4), investment internal rate of return (Y5), and level of scientific publications (Y6). We would have added another variable—the ratio of students to teaching staff, as a proxy for the quality of HE. However, this data was missing for 12 countries. Thus, this ratio was not included. In relation to the studies on OECD countries' efficiency cited above, our study has more variables (8), including more aspects: accessibility, employability, economic value, and research.

Treatment of missing data is discussed in Appendix 1. Due to missing too much data we included only 29 OECD countries. A transformation was done for each variable, so that the maximal value of each input/output variable will be 100. Thus, the weights of variables (Vi, Ui) are comparable and reflect the relative intensity of each variable and its weight regarding its contribution to the overall efficiency.

16.4 Results

This section presents the results of the two main DEA efficiency methods, CRS and VRS, with their weights improvement and benchmark analyses. Then, the feasible SE and CE for CRS rank-scale efficiency results are presented. Finally, the feasible multivariate statistical rank-scaling efficiency results are presented, as applied to our OECD study.

16.4.1 CRS Efficient and Inefficient Countries

As shown in the first column of Appendix 2, Table 16.10, CRS efficiency results indicate that 10 countries are efficient among OECD countries: Chile, Hungary, Ireland Israel, Italy, Korea, Luxembourg, Portugal, the United Kingdom, and the USA. The other 19 countries are inefficient. CRS efficiencies range here in the interval [0.570, 1]. For CRS efficient countries the efficiency value is 1, while for CRS inefficient countries the efficiency value is less than 1.

Weights: The ideal weights of the inputs and outputs vary greatly from one country to another as presented in Appendix 2, Table 16.8 (For example, Australia has an ideal weight of 0.0108 for output 5 and zero for all other outputs, while the USA has an ideal weight of 0.01 for output 6 and zero to all other outputs.). Most of the inefficient countries had positive weights for outputs Y1 and Y2 (12 and 14 inefficient countries, respectively)—reflecting their relative strength in percent of adults attaining HE (Y1) and percent of adults employed (Y2), which are two of the main objectives of countries from public HE (as shown in Sect. 16.8).

There is a strong relationship between the weights of the inputs/outputs and the improvements. Whenever a country has a positive weight for a certain variable, the improvement this variable needs is zero, and whenever a country needs an improvement in a certain variable the weight of this variable is zero (this is the complementary slackness rule).

Improvements: The inefficient countries need improvements in some of the outputs in which they are weak. As shown in Appendix 2, Table 16.10 most of the 19 inefficient countries needed improvements in outputs Y3, Y4, Y5, Y6—the number of countries which needed improvements in these variables are 14,13,16, and 12 countries, respectively. This indicates that accessibility has been reached (Y1, and Y2), while the economic gain is not necessarily achieved (Y3, Y4, Y5). (Nor is the research excellence achieved (Y6—country h index).) Economic gain is where most inefficient countries need improvements (Appendix 2, Table 16.10). This is the reason for our discussion in Sect. 16.8 on accessibility and employment (Fig. 16.1).

Most of the efficient countries were strong in at least one of these variables. Moreover, out of the 10 efficient countries, 7 countries became efficient because they had a relative advantage in only one of these 4 specific outputs (Y3, Y4, Y5, Y6), as reflected by the positive weights they received to one of those outputs. For example, the USA has a positive weight for output Y6 (0.01 weight) and zero to all other outputs (Appendix 2, Table 16.8).

Benchmark analyses: Appendix 2, Table 16.12 presents for each inefficient country the efficient countries that caused it to be relatively inefficient, those who have positive λ value (dual variables). For example, Slovak Republic is inefficient because of two countries: Hungary ($\lambda = 0.895$) and United Kingdom ($\lambda = 0.07$).

16.4.2 VRS Efficient and Inefficient Countries

As shown in the second column of Table 16.2 VRS (variable return to scale) efficiency shows additional 7 efficient countries: Australia, Canada, Germany, Latvia, Netherlands, Slovenia, and Switzerland, in addition to the previous 10 countries. Altogether 17 countries are VRS efficient—VRS takes into account return to scale of the countries, while the remaining 12 countries are VRS inefficient. Appendix 2, Table 16.9 presents the variability of VRS weights of the input and output variables from one country to another, by presenting their ranges (from zero

Table 16.2 Efficiencies of OECD countries via several methods

Method:	Case of 2 inputs			Case of 1 inputs			
Country:	SE-CRS[a]	VRS[b]	CE-CRS	SE-CRS[a]	VRS[b]	CE-CRS	Disc. VRS
Australia	0.918	1	0.7508	0.592	0.670	0.4879	−0.649
Austria	0.594	0.594	0.4797	0.392	0.475	0.3426	−0.913
Belgium	0.801	0.856	0.6706	0.705	0.856	0.5851	−0.094
Canada	0.881	1	0.6120	0.599	1	0.4446	−0.325
Chile	1.321	1	0.5153	0.348	1	0.2349	1.758
Czech Repub.	0.901	0.936	0.7038	0.797	0.936	0.5934	0.178
Denmark	0.602	0.667	0.4437	0.420	0.615	0.3091	−1.901
Finland	0.642	0.646	0.4953	0.478	0.621	0.3730	−0.849
France	0.878	0.985	0.6942	0.878	0.985	0.7395	0.455
Germany	0.739	1	0.6290	0.678	1	0.5993	1.540
Hungary	1.138	1	0.8633	0.954	1	0.7558	1.100
Ireland	1.137	1	0.8093	0.900	1	0.6476	2.501
Israel	1.175	1	0.8926	0.908	1	0.7250	1.514
Italy	1.232	1	0.8644	1.232	1	0.9594	−1.380
Korea	1.036	1	0.7114	0.571	0.705	0.4257	−2.086
Latvia	0.941	1	0.7401	0.715	1	0.5055	−0.298
Luxembourg	2.697	1	0.8374	2.697	1	0.9545	0.964
Netherlands	0.886	1	0.6443	0.498	1	0.4374	1.305
New Zealand	0.774	0.956	0.5978	0.374	0.576	0.3250	−1.377
Norway	0.570	0.910	0.4061	0.363	0.910	0.2540	−2.051
Poland	0.758	0.917	0.6050	0.535	0.887	0.4650	0.047
Portugal	1.007	1	0.8552	0.879	1	0.6942	1.006
Slovak Repub.	0.837	0.854	0.6424	0.643	0.683	0.4527	−1.069
Slovenia	0.831	1	0.6911	0.663	1	0.5420	0.957
Spain	0.884	0.902	0.7018	0.766	0.797	0.6370	−0.462
Switzerland	0.626	1	0.4528	0.474	1	0.3348	−0.461
Turkey	0.586	0.589	0.4449	0.411	0.446	0.2773	−2.548
UK	1.283	1	0.8912	0.723	1	0.6191	0.487
USA	1.742	1	0.9743	1.144	1	0.8684	2.649

[a]SE-CRS column also presents CRS efficiency—all efficiencies which are more than 1 have efficiency 1 for CRS
[b]Some of the countries have infeasible efficiency in SE-VRS column thus only VRS is presented

to the maximal value over all the countries) for CRS too. Appendix 2, Table 16.13 presents some benchmark analysis for VRS and CRS—the number of countries for which each efficient country served as a benchmark. We used the VRS dichotomy of efficient and inefficient (column 2 of Table 16.2) for the Discriminant analysis efficiency scaling.

Table 16.3 Coefficients of Canonical and Discriminant analysis for CRS and VRS efficiencies

Coefficient of:	X1	X2	Y1	Y2	Y3	Y4	Y5	Y6
Case of 2 inputs								
CCA	0.012	−0.046	0.013	−0.044	0.022	−0.029	0.038	0.021
Disc-CRS	−0.648	−0.068	0.039	0.014	0.030	0.000	−91.372	2.190
Disc-VRS	−0.331	−0.079	0.056	0.135	0.026	0.000	−54.772	0.898
Case of 1 input								
CCA	0.395		0.500	−0.295	0.231	−0.539	−0.019	0.455
Disc-CRS	−0.036		−0.003	−0.173	0.021	0.041	−0.035	0.035
Disc-VRS	−0.022		0.024	0.139	0.113	0.013	0.017	0.018

16.4.3 SE-CRS and SE-VRS Rank-scaling Efficiency Methods

As shown in the first column of Table 16.2, the *Super Efficiency* of CRS (SE-CRS) gets efficiency values of 1 and beyond up to 2.6967 in our study. The country with the minimal relative CRS efficiency is Norway (0.57); while the country with the maximal *SE-CRS* efficiency is Luxembourg (2.697).

SE-VRS was not feasible in this OECD case study, since for 10 countries SE-CRS values were infeasible. Thus SE-VRS is not considered in our case study.

16.4.4 CE-CRS and CE-VRS Rank-scaling Efficiency Methods

The *Cross Efficiency* (CE) is given in the third column of Table 16.2, *CE-CRS*. The values of CE range here are in the interval [0.4061, 0.9743], the USA received the maximal value, and Norway received the minimal CE-CRS. Due to some negative values of the constant of VRS, CE-VRS is not feasible here.

16.4.5 Multivariate Efficiency Results

As shown in Table 16.3, *Canonical Correlations* Analysis (CCA) is infeasible here, since some of its coefficients are negative, implying that X2 contributes negatively to the sum of weighted inputs, and outputs Y2 and Y4 contribute negatively to the sum of weighted outputs.

Disc-CRS *Discriminant* (Disc) analysis based on CRS dichotomy (efficient and inefficient), is infeasible rank-scale efficiency method due to the negative coefficient of Y5, as shown in Table 16.3.

For the same reason, **Disc-VRS** efficiency method, based on VRS dichotomy, is also infeasible as shown in Table 16.3.

16.5 The Case of 1 Input

One can argue that X2, "Percentage of public sources from total HE expenditure," should not be an input, since when X2 decreases, it implies that X1 composes a smaller percentage of the total income of HE, implying that "percentage of Government expenditure allocated for HE" has a higher percentage of HE income—from the private sector, which further benefits HE, beyond the public amount allocated to it. For example, if in a certain country X1 = 3%, which is a public allocation to HE of 10 billion dollars and it composes 40% = X2 of the total expenditure of HE in that country, then the total allocation to HE is 25 billion dollars. However, if for the above X1 = 3%, the 10 billion dollars are only 25% = X2 of the total allocation to HE, then the total budget of HE is 40 billion dollars. Since we analyze the efficiency from the viewpoint of the public, the resolution is to drop X2 altogether. Consequently, we also considered the case of only 1 input, X1, with the above six outputs.

For the case of 1 input, the results in Table 16.2 for the SE-CRS column, also represent the CRS division to efficient and inefficient. Wherever a country has SE-CRS > 1 it means that its CRS efficiency is 1, thus it is an efficient country. Consequently, SE-CRS shows that only 3 countries are CRS efficient: Italy, Luxemburg, and the USA. The country with the maximal SE-CRS rank-scale efficiency is Luxembourg with SE-CRS efficiency of 2.697.

As shown in Table 16.2 for the case of 1 input, the maximal value for CE-CRS efficiency rank-scale is 0.9594 in this case, for Italy—the leading country, Luxembourg has the second highest efficiency rank-scale (0.9545), and the USA has the third CE-CRS efficiency rank-scale (0.8684), etc.

As expected, in relation to CRS, more countries are VRS efficient—12 additional countries: Canada, Chile, Germany, Hungary, Ireland, Israel, Latvia, Netherlands, Portugal, Slovenia, Switzerland, and the United Kingdom. However, 10 countries had infeasible SE-VRS value, thus we could not use the SE-VRS efficiency method in this OECD application. Also, CE-VRS is infeasible in this case. Nevertheless, we were able to utilize the VRS dichotomy of efficient and inefficient for the Discriminant analysis efficiency scaling.

Variability of the weights is shown in Appendix 2, Table 16.9, for CRS and VRS inputs and output, which vary greatly from country to country for both cases: with 2 inputs and with 1 output. It is hard to point strongly at the dominant output, Y2 has the maximal number of positive weights for the case of 2 inputs (18 for CRS and 17 for VRS), but Y6 has the maximal number of positive weights for the case with 1 input—27 for CRS and 22 for VRS. Y1, reflecting high accessibility of HE (percent of adults attained HE) has a relatively high number of positive weights over all the models (CRS and VRS) for the two cases (2 inputs and 1 input)—between 12 and 15 countries had positive weights. This finding led to devote Sect. 16.8 to the danger that oversupply of HE may reduce the economic value of HE.

Improvements for the case of 1 input concentrate mainly on Y3, Y4, Y5, for CRS model and VRS model. In common with the case of 2 inputs, these outputs represent the economic gains from HE for the public (see Appendix 2, Table 16.11). The improvements of other outputs vary greatly among the various models.

Benchmark analysis, as summarized in Appendix 2, Table 16.14, shows that for both CRS and VRS Luxembourg serves most often as peer to inefficient countries (27 countries in CRS, and for 12 countries in VRS), for the case of 1 input. For the case of 2 inputs, as summarized in Appendix 2, Table 16.13 other efficient countries are most often peers of inefficient countries (Hungary serves a peer for 15 countries in CRS, and Israel serves as a peer for only 7 countries in VRS).

Multivariate analysis for the case of 1 input: As shown in Table 16.3, CCA is infeasible, due to negative weights for Y2, Y4, and Y5. As shown in Appendix 3, we tried to use regression analysis (REG), but the weights of output Y2 and output Y4 are negative. Thus, REG efficiency method is infeasible here. Disc-CRS is infeasible since the weights of Y1, Y2, and Y5 are negative. However, Disc-VRS is feasible since all the outputs have positive weights; while the 1 input has negative weight as required. In summary, from all multivariate statistical efficiency methods, only Disc-VRS efficiency for the case of 1 input is feasible, as reported in the last column of Table 16.2. The USA has the highest Disc-VRS efficiency (2.649), while Turkey has the lowest Disc-VRS efficiency (−2.548).

16.6 Robust Solution

In summary, the 7 methods listed in Table 16.4 were considered, whenever relevant and feasible.

For the case of 2 inputs, two efficiency rank-scale methods were feasible for OECD countries: SE-CRS and CE-CRS.

For the case of 1 input, three efficiency rank-scale methods were feasible for OECD countries: SE-CRS, CE-CRS, and Disc-VRS. The nominal efficiency values are detailed in Table 16.2.

All together 5 efficiency rank-scales were feasible. The robust efficiency method is the one with the highest average correlation with all other feasible efficiency methods (Sinuany-Stern & Friedman, 2021).

Appendix 5 presents the Pearson and Spearman rank correlations between all pairs of the five feasible efficiency scale rank methods for our OECD efficiency study (the ranks of the OECD countries for each of the 5 feasible efficiency methods are given in Appendix 4). Based on these correlations the average correlation of each method with the other four methods was calculated (see Table 16.5). The highest average correlation points at the robust method for our study. In our OECD study, CE-CRS is the robust efficiency method with average correlation of 0.727 (the average of Pearson and Spearman correlations) for the case of 2 inputs. Also, for the case of 1 input CE-CRS is the robust method with average correlation of 0.735. The use of the average between Pearson and Spearman correlation is necessary when the robust method is not identical in both correlations, as happens here for both cases.

Table 16.4 Rank scale efficiency methods considered and their feasibility[a]

Efficiency method	SE-CRS	CE-CRS	SE-VRS	Canonical	Disc-CRS	Disc-VRS	Regression
The case of 2 inputs	Y	**YY**	N	N	N	N	NN
The case of 1 input	Y	**YY**	N	N	N	Y	N

[a]N—considered method but not feasible, NN—not considered method at all, Y—yes feasible method, **YY**—Robust feasible method

Table 16.5 Average correlations of each efficiency rank scale with all other efficiency models

	The case of 2 inputs		The case of 1 input		
Correlation type[a]	SE-CRS	CE-CRS	SE-CRS	CE-CRS	Disc-VRS
Pearson	0.678[b]	0.677	0.667	0.716[b]	0.525
Spearman	0.688	0.777[b]	0.761[b]	0.755	0.520
Average correlation	0.683	0.727[b]	0.714	0.735[b]	0.523

[a]The calculations are based on Appendix 5—each entry is an average of 4 correlations in the Appendix
[b]The highest average correlations

16.7 Other Explanatory Factors Affecting the Efficiency

After finding the robust solution CE-CRS method, an attempt was made to find external explanatory factors which may be correlated with CE-CRS.

The seven explanatory factors are:

Z1—Percentage of foreign and international students (Source: OECD, 2019, Table B6.1 Col. 6)
Z2—Gross National Income (GNI) (Source: UN, 2019, last col. Of table)
Z3—Human Development Index (HDI, source as Z2, first column ibid)
Z4—Cost–Benefit ratio (Source: OECD, 2019, Tables A5.2, col. 6/col. 3)
Z5—1 for English speaking country, 0 otherwise
Z6—European country 1, non-European 0
Z7—Z1 × Z5
Z8—Global competitiveness index 4.0 (Schwab, 2019)

As shown in the above list, external factors, Zi, were taken from various sources. Our basic hypothesis was that all 8 factors, Zi, will be positively correlated with the efficiency CE-CRS. In fact, as shown in Table 16.6, the correlations between the robust efficiency method CE-CRS and each of the Zi factors reveals that only Z4 (benefit/cost), and Z5 (English speaking countries) are positive significantly (R4 = 0.509 with P-value < 0.01 and R5 = 0.318 with P-value < 0.05) for the case of 2 inputs. However, for the case of 1 input, only the correlation of CE-CRS with Z4 (benefit/cost) is positive significantly ($R = 0.338$ with P-value < 0.05). All the correlations with the other Zi are not significant. Appendix 6 provides the data of all the factors.

Table 16.6 Explanatory variable Zi Pearson correlation with CE-CRS (the robust method)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8
CE-CRS	0.131	−0.100	−0.098	0.509[b]	0.318[c]	−0.043	0.202	−0.025
CE-CRS[a]	0.246[d]	0.085	−0.058	0.338[c]	0.072	0.199	−0.062	0.005

[a]The case with 1 input
[b]*P* value less than 0.01
[c]*P* value less than 0.05
[d]*P* value less than 0.1

16.8 Possible Risks of Over Access of HE

Higher Education (HE) is an indication of the human development of a country. Thus, there is an urge to increase HE enrollments, as shown in the previous paragraphs. However, the quest for increasing the number of students and graduates, to increase their future income, may backfire when there is an excess of enrollments in HE, as shown below.

Consider a simplified supply and demand model for HE, on the national level, where demand for HE is a function of tuition (Sinuany-Stern, 1991). As shown in Fig. 16.1a, in the HE market with supply and demand curves, the equilibrium point in a free market will be at the point (Q1’, P1’) where Q1’ is the number of enrolled students and P1’ is the tuition. Figure 16.1b shows the market of graduates as a function of wage. The associated supply and demand curves show the corresponding equilibrium at the point (Q2’, P2’) with Q2’ graduates employed getting a wage of P2’.

However, if the government subsidizes HE, as shown in the lower dotted supply curve in Fig. 16.1a, then the new enrollment level at the equilibrium point will grow to Q1”, and the new tuition will be reduced to P1”. This rise in enrollment level will eventually increase the number of graduates who will enter the workforce to Q2”. More enrollment yields more graduates (see Fig. 16.1b, the new graduates’ supply curve in the dotted line). This results in a decrease of the wage to P2”. Lower wages, in return, reduce the value of HE. Thus, in the long run, it may affect enrollment and reduce it to Q1”’ (in extreme cases, even, less than its original equilibrium Q1’). Moreover, the wage will reduce now to P2”; thus, reducing the economic value of HE.

Yet another scenario could be, that, if the government forces wages to the higher original level of P2’ (greater than the new equilibrium level, P2”), there will be unemployment of Q2”- Q2’, unless other actions are taken.

In summary “credentialism” is the result of the quest for excessive increase of HE. Credentialism (the value of a degree) was defined by Dore (1976) as emphasis placed by students or employers, on the piece of paper certifying a student, rather than on mastery of a subject or a profession. The propensity to appreciate the significance of a certificate—more than the skills themselves—creates a kind of vicious cycle in which increasingly advanced degrees are required in the attempt to compensate for the diminishing value of the academic certificate (Davidovitch et al.,

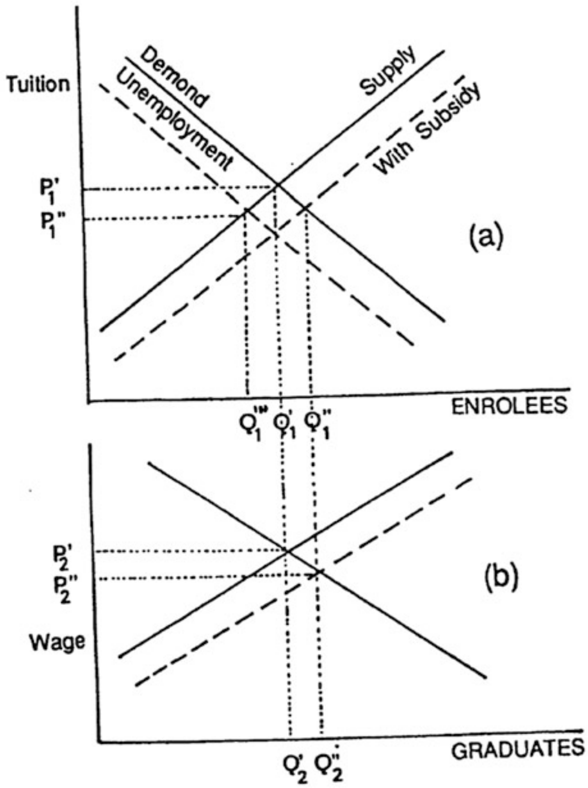

Fig. 16.1 Supply and demand for HE enrollment (**a**) and graduates (**b**) (Sinuany-Stern, 1991)

2012). Similarly, Altbach et al. (2017) wrote about the massification of HE and its implications—toward differentiation in HE. For example, Pietrzak (2021) describes a similar process about the massification of HE in Poland, where the college age group grew from 13% in 1988 to its peak of 54% in 2010 and decreased to 46% by 2019.

This process occurs when employers believe that education "improves" employee quality. Thus, when they hire an individual with a degree—more advanced than typically required—they are getting more for their money. This belief led employers to demand a bachelor's and a master's degree from employees for the same previous salary (see Davidovitch et al., 2013; Lindberg, 2007). This indicates that accessibility has been reached, while the economic gain is not necessarily so.

Schwab and Davis (2018) point at the job generators industries needed for the fourth industrial revolution. However, sometimes there are discrepancies between the demand of the industry for HE graduates and the supply of HE graduates in specific professions, which may result in local over supply of graduates in some professions and shortage in other professions.

16.9 Summary and Conclusions

In this chapter, the efficiency of higher education (HE) in 29 OECD countries was studied from the public viewpoint. From 7 efficiency methods considered for the case of 2 inputs and 6 outputs only two methods were feasible: SE-CRS (super efficiency of constant return to scale efficiency) and CE-CRS (cross efficiency of constant return to scale efficiency). The robust method, in this case, is CE-CRS. The leading country is the USA.

For the case of 1 input and the same 6 outputs, three efficiency methods were feasible: SE-CRS, CE-CRS, and Discriminant-VRS. Again CE-CRS turned to be the robust efficiency method. The leading country is Italy, while the USA is ranked in third place (in the previous case Italy is ranked fourth). Four multivariate statistical efficiency methods were considered, almost all of them were not feasible in all cases. Only discriminant-VRS efficiency in the case of 1 input was feasible.

As a second stage, to explain the robust efficiency, other 8 possible external explanatory factors were tested for positive correlation (Hypothesis). Only two factors were correlated significantly positively with the robust efficiency rank-scale, CE-CRS: 1. benefit/cost of HE of the country and 2. whether the country is English speaking. Other six factors had insignificant very small correlations with CE-CRS: 1. percent of international students, 2. Global competitiveness index, 3. Gross National Income, 4. Human Development Index, and 5. Multiplication of percent of international students with English speaking country.

Besides being the robust efficiency method based on the average correlation criterion, CE-CRS efficiency method has the advantage that each country is evaluated with the input and output weights of all the other countries, which is a fair comparable comparison. While SE-CRS uses for each country only its own ideal input and output weights. Thus, the countries are not compared with the same weights. Although the correlation between the two efficiency methods (SE-CRS and CE-CRS) is statistically significant.

We found that the first output, reflecting high accessibility of HE (percent of adults attained HE) has a relatively high number of positive weights over all the models used here (CRS and VRS) for the two cases (2 inputs and 1 input). Therefore, we show by supply and demand curves of the HE market and the job market that, increasing enrollments on the national level (e.g., by offering significant grants) may cause oversupply of graduates in the job market, which may cause unemployment of graduates or wage decline, which may reduce the economic value of HE, and may reduce enrollments in the long run. Indeed, we found that, in all the models (CRS and VRS) and in the two cases of 2 inputs and 1 input, the improvements that the inefficient countries need to perform concentrate mainly on the three outputs that represent economic gains from HE: earnings level relative to secondary education, net financial returns from HE and internal rate of return from HE.

For future research, other types of efficiency models and variables can be applied (e.g., De Witte & Lopez-Torres, 2017), including efficiency over time, such as the Malmquist productivity index. Moreover, other outputs of government expenditure for HE could be considered, such as foreign students as an export market for HE, and patents as another research output; and other inputs such as public investment per student. While our study evaluated the efficiency of OECD countries from the public viewpoint, there is a need to perform a parallel study from the private viewpoint.

We are yet to see the long-run influence of the current crisis of the COVID-19 pandemic on OECD countries in general and on various aspects of HE on the national level such as governments investment in HE, enrollments level, unemployment of graduates, globalization, and international students' exchange, and online learning. Such changes may change the efficiency of HE significantly in 2020 and in future years.

Appendix 1: OECD data sources

All inputs and outputs data except Y6 were taken from the OECD education 2019 report, taken from: http://meyda.education.gov.il/files/MinhalCalcala/EAG2019.pdf (accessed on May 12, 2020)

Inputs sources:

X1—Table C4.1 column 11 (2016 data)
X2—Table C3.1 column 6 (2016 data)

Outputs sources:

Y1—Table A1.1 as the sum of columns 8,9,10,11 Ed. Attainment in % of age 25–64 (2018 data)
Y2—Table A3.1 column 9 Employment rate (%) from age 25–64 years (2018 data)
Y3—Table A4.1 column 6 Relative earning of workers by educational attainment (2017 data)
Y4 and Y5 were calculated from columns 7 and 8, respectively of Tables A5.2a (for man), and A5.2b (for woman) weighted average where men and women rates by country were taken from Figure A1.4 (2016 data)
Y6—Cimcago h index by country (https://www.scimagojr.com/countryrank.php), accessed on May 2020)

Note that a transformation was done for each variable so that the maximal value of each input/output variable will be 100.

Treatment of missing data:

Overall, 8 countries were deleted due to problems with data—mainly missing data.
In the first stage, countries with more than 2 missing values were deleted: Columbia, Greece, Iceland, Lithuania, Mexico, Japan, and Sweden.
At the second stage, Estonia was deleted due to a negative value of Y4.
At the third stage, there were 3 countries with at most 2-missing data—altogether 4 numbers were missing, as follows: data from previous years was taken wherever possible, in addition, Mice package was used to estimate the missing value using

Table 16.7 Summary of missing values treatment and new values

	Past year value[a]	Mice missing values procedure	New value for 2019[b]
Denmark[b]	X1 = 4.2 (2017) Table B4.1	3.2	3.708
	X2 = 95 (2017) Table B3.1	84.5	89.793
Slovenia[b]	Y3 = 171 (2017) Table A6.1	157.8	164.4
Switzerland	X2 is Missing for 2014–2019	84.24	84.24

[a]Previous year report where data is available
[b]The value is the average between the first two columns

the given complete data of 2019. The final value was an average of the value from the Mice package and the old value found prior to 2019. At this stage:
X1 was missing for Denmark and Switzerland
X2 was missing for Switzerland
Y3 was missing for Slovenia

Note that, for all the calculations, a transformation was done for each variable so that the maximal value of each input/output variable will be 100. Thus, the calculated weights are comparable for the various inputs and outputs.

Appendix 2

Table 16.8 CRS weights of inputs (Vi)/outputs (Ur) for each country, for the case of 2 inputs

	V1	V2	U1	U2	U3	U4	U5	U6
Australia[b]	0.0093	0.0087	0	0	0	0	0.0108	0
Austria	0.0073	0.0051	0.0010	0.0051	0	0.0010	0	0
Belgium	0.0106	0.0052	0.0001	0.0033	0	0.0020	0.0042	0.0002
Canada	0.0087	0.0066	0.0086	0	0	0	0	0.0004
Chile[a]	0.0062	0.0099	0	0	0.0100	0	0	0
Czech Repub.	0.0180	0.0052	0	0.0093	0.0001	0	0	0
Denmark	0.0074	0.0051	0.0011	0.0054	0	0	0	0
Finland	0.0094	0.0043	0.0017	0.0051	0	0	0	0.0006
France	0.0248	0	0.0035	0	0.0031	0	0	0.0092
Germany[b]	0.0086	0.0061	0	0.0051	0.0014	0.0021	0	0.0001
Hungary[a]	0.0100	0.0104	0	0	0.0133	0	0	0
Ireland[a]	0.0111	0.0060	0	0.0038	0	0.0022	0.0045	0
Israel[a]	0.0183	0.0036	0	0	0	0	0.0117	0
Italy[a]	0.0150	0.0089	0.0023	0.0097	0	0	0	0.0012
Korea[a]	0.0118	0.0089	0.0118	0	0	0	0	0
Latvia[b]	0.0116	0.0080	0.0018	0.0085	0	0	0	0
Luxembourg[a]	0.0064	0.0088	0	0	0	0.0100	0	0
Netherlands[b]	0.0057	0.0079	0	0	0	0.0090	0	0
New Zealand	0.0088	0.0073	0	0.0079	0	0	0	0
Norway	0.0068	0.0047	0.0010	0.0050	0	0	0	0
Poland	0.0095	0.0065	0.0014	0.0069	0	0	0	0
Portugal[a]	0.0122	0.0089	0	0.0071	0	0.0011	0.0039	0
Slovak Rep.	0.0101	0.0084	0	0.0091	0	0	0	0
Slovenia[b]	0.0101	0.0069	0.0016	0.0069	0	0.0012	0	0
Spain	0.0144	0.0060	0.0028	0.0060	0.0014	0	0	0.0017
Switzerland[b]	0.0079	0.0048	0.0012	0.0052	0.0000	0	0	0.0005
Turkey	0.0072	0.0047	0	0	0.0035	0	0.0043	0
UK[a]	0.0127	0.0076	0.0020	0.0082	0	0	0	0.0010
USA[a]	0.0174	0	0	0	0	0	0	0.0100

[a]CRS and VRS efficient
[b]Only VRS efficient

Note that, for all the calculations, a transformation was done for each variable so that the maximal value of each input/output variable will be 100. Thus, the calculated weights are comparable for the various inputs and outputs

Table 16.9 Weights' maximal value[a] for CRS and VRS and number of countries with positive weight, for the case of 2 inputs and for the case of 1 input

	V1	V2	U1	U2	U3	U4	U5	U6
Case of 2 inputs								
CRS max. Weight	0.025	0.0103	0.012	0.009	0.013	0.01	0.012	0.01
# posit. weights[b]	29	27	15	18	7	9	6	10
VRS max. weight	0.030	0.0155	0.050	0.451	0.013	0.014	0.028	0.022
# posit. weights[b]	29	23	14	17	9	6	6	13
Case of 1 input								
CRS max. weight	0.047		0.005	0.002	0.010	0.01	0.014	0.014
# posit. weights[b]	29		12	7	7	3	11	27
VRS max. weight	0.047		0.071	0.451	0.033	0.034	0.013	0.045
# posit. weights[b]	29		15	16	7	4	9	22

[a]Note that a transformation was done for each variable so that the maximal value of each input/output variable will be 100

[b]Number of countries with positive weights, the rest have zero weight

Table 16.10 Improvement[a] for input/output by country for CRS efficiency: the case of 2 inputs

	CRS	SX1	SX2	SY1	SY2	SY3	SY4	SY5	SY6
Australia	0.918	0	0	8.344	9.527	11.903	0	0	24.161
Austria	0.594	0	0	0	0	11.155	0	26.755	15.466
Belgium	0.801	0	0	0	0	16.975	0	0	0
Canada	0.881	0	0	0	12.910	12.664	4.216	14.493	0
Chile	1	0	0	0	0	0	0	0	0
Czech Republic	0.901	0	0	0.507	0	0	20.225	17.546	8.633
Denmark	0.602	0	0	0	0	16.459	13.068	47.608	0.673
Finland	0.642	0	0	0	0	8.364	12.325	41.215	0
France	0.878	0	1.728	0	1.102	0	36.616	13.604	0
Germany	0.739	0	0	8.889	0	0	0	14.565	0
Hungary	1	0	0	0	0	0	0	0	0
Ireland	1	0	0	0	0	0	0	0	0
Israel	1	0	0	0	0	0	0	0	0
Italy	1	0	0	0	0	0	0	0	0
Korea	1	0	0	0	0	0	0	0	0
Latvia	0.941	0	0	0	0	12.913	19.544	9.568	17.508
Luxembourg	1	0	0	0	0	0	0	0	0
Netherlands	0.886	0	0	39.729	20.672	29.258	0	22.987	64.885
New Zealand	0.774	0	0	2.465	0	9.775	12.935	23.225	28.231
Norway	0.570	0	0	0	0	15.970	19.926	55.407	8.963
Poland	0.758	0	0	0	0	9.293	11.939	17.930	2.903
Portugal	1	0	0	0	0	0	0	0	0
Slovak Republic	0.837	0	0	1.897	0	3.004	17.308	21.784	9.386
Slovenia	0.831	0	0	0	0	5.838	0	7.5165	11.082
Spain	0.884	0	0	0	0	0	31.412	21.3059	0
Switzerland	0.626	0	0	0	0	1.432	27.548	57.5707	0
Turkey	0.586	0	0	46.934	10.262	0	11.909	0	51.517
UK	1	0	0	0	0	0	0	0	0
USA	1	0	0	0	0	0	0	0	0
Max. slack		0	1.73	46.93	20.67	29.26	36.62	57.57	64.88
Slacks no.[b]		0	1	7	5	14	13	16	12

[a]The improvement (slack) required for each input/output
[b]The number of countries that need positive improvement (slack) for an input/output

The DEA version used here is *output oriented*, which means that most of the improvements concentrate on the outputs, thus most of the inputs have positive weights as presented in Appendix 2, Table 16.9 for CRS and VRS versions of DEA. The improvements are in percentages

Table 16.11 Number of countries that need improvements for CRS/VRS in case 1 and case 2

	The case of 2 inputs		The case of 1 input	
	CRS	VRS	CRS	VRS
X1	0	0	0	0
X2	1	4	NA	NA
Y1	7	6	15	6
Y2	5	3	20	5
Y3	14	7	19	10
Y4	13	11	24	13
Y5	16	10	15	11
Y6	12	5	1	2

Table 16.12 Benchmark[a] of CRS efficiency: the case of 2 inputs

Eff. Dept./ Ineff. Dept.	Chile	Hungary	Ireland	Israel	Italy	Korea	Luxem-bourg	Portugal	UK	USA
Australia	0	0	0	0.183	0	0	0	0	0.782	0.115
Austria	0	0.345	0	0	0	0	0.043	0.319	0	0.300
Belgium	0	0.152	0.340	0.016	0	0	0.177	0.137	0	0.186
Canada	0	0	0.	0.173	0	0.785	0	0	0	0.224
Czech Repub.	0	0.627	0	0	0.367	0	0.040	0	0	0
Denmark	0	0.491	0	0.298	0	0	0	0	0.230	0
Finland	0	0.178	0	0.744	0.032	0	0.050	0	0	0
France	0	0	0	0	0.393	0	0.347	0	0	0.297
Germany	0	0.162	0	0	0.393	0	0.133	0.064	0	0.318
Latvia	0	0.712	0	0.279	0	0	0	0	0.041	0
Netherlands	0	0	0	0	0	0	0.252	0	0	1.06
New Zealand	0	0.296	0	0	0	0	0	0	0.727	0
Norway	0	0.295	0	0.498	0	0	0	0	0.236	0
Poland	0	0.814	0	0.083	0	0	0	0	0.136	0
Slovak Republic	0	0.895	0	0	0	0	0	0	0.070	0
Slovenia	0	0.733	0	0.070	0	0	0.170	0	0	0.063
Spain	0	0.270	0	0.238	0.099	0	0.162	0	0	0.196
Switzerland	0	0.049	0	0.529	0.213	0	0	0	0.250	0
Turkey	0	0.018	0	0.399	0	0	0	0	0	0.573

[a]In the table, the λ values are the weights given by efficient country to inefficient country. The 10 countries at the top titles of the columns are the efficient countries, while the first column presents the inefficient countries

Table 16.13 Benchmark[a] analysis for the case of 2 inputs for CRS and VRS

Efficient country j	No. of times as peer[a] for CRS	Max. value[a] of λ for CRS	No. of times as peer[a] for VRS	Maximal value[a] of λ for VRS
Chile	0	0	0	
Hungary	15	0.895	6	0.520
Ireland	1	0.340	1	0.378
Israel	12	0.744	7	0.702
Italy	6	0.393	2	0.383
Korea	1	0.785	0	NA
Luxembourg	9	0.347	6	0.471
Portugal	3	0.319	6	0.527
UK	8	0.782	3	0.484
USA	10	0.573	8	0.497
Australia			0	NA
Canada			0	NA
Germany			4	0.283
Latvia			3	0.501
Netherlands			3	0.452
Slovenia			1	0.116
Switzerland			2	0.861

[a]Two parameters are used for benchmark: the number of appearances of an efficient country j as peer of other inefficient countries (namely λj is none zero), and the maximal value of λj

Table 16.14 Benchmark[a] analysis for CRS and VRS—the case of 1 input

Efficient country	CRS		VRS	
	Number of times a country is benchmark of others	Range of $\lambda > 0$ for CRS	Number of times a country is benchmark of others	Range of $\lambda > 0$ for VRS
Italy	24	0.936	4	0.179
Luxembourg	27	0.888	12	0.695
USA	14	0.429	9	0.369
Canada			0	
Chile			0	
Germany			8	0.362
Hungary			5	0.484
Ireland			4	0.611
Israel			8	0.703
Latvia			0	
Netherlands			1	0.093
Portugal			3	0.527
Slovenia			4	0.739
Switzerland			1	0.861
UK			0	

[a]CRS is constant return to scale, VRS is variable return to scale, λ is a dual variable representing the maximal influence that an efficient country has on another inefficient country

Appendix 3: Regression of X1 with the 6 outputs

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	4.336e + 1	1.020e + 2	0.425	0.675
Y1	4.781e−1	4.484e−1	1.066	0.298
Y2	−3.548e−1	1.102e + 0	−0.322	0.750
Y3	1.670e−1	2.040e−1	0.819	0.422
Y4	−6.901e−5	6.324e−5	−1.091	0.287
Y5	1.576e + 1	1.746e + 2	0.090	0.929
Y6	6.263e−3	9.763e−3	0.642	0.528

Residual standard error: 19.81 on 22 degrees of freedom
Multiple R-squared: 0.1557, Adjusted R-squared: −0.07456
F-statistic: 0.6762 on 6 and 22 DF, p-value: 0.6702

Appendix 4: Efficiency[a] ranks of OECD countries

	Case of 2 inputs		Case of 1 input		
Country	SE-CRS	CE-CRS	SE-CRS	CE-CRS	Disc.-VRS
Australia	12	9	18	16	20
Austria	27	25	26	23	22
Belgium	20	16	13	13	15
Canada	16	20	17	19	17
Chile	3	23	29	29	3
Czech Republic	13	12	9	12	13
Denmark	26	28	24	26	26
Finland	24	24	22	22	21
France	17	14	8	5	12
Germany	23	19	14	11	4
Hungary	7	5	4	4	7
Ireland	8	8	6	8	2
Israel	6	2	5	6	5
Italy	5	4	2	1	25
Korea	9	11	19	21	28
Latvia	11	10	12	15	16
Luxembourg	1	7	1	2	9
Netherlands	14	17	21	20	6
New Zealand	21	22	27	25	24

(continued)

Country	Case of 2 inputs		Case of 1 input		
	SE-CRS	CE-CRS	SE-CRS	CE-CRS	Disc.-VRS
Norway	29	29	28	28	27
Poland	22	21	20	17	14
Portugal	10	6	7	7	8
Slovak Republic	18	18	16	18	23
Slovenia	19	15	15	14	10
Spain	15	13	10	9	19
Switzerland	25	26	23	24	18
Turkey	28	27	25	27	29
UK	4	3	11	10	11
USA	2	1	3	3	1

[a]In each column rank 1 represents the highest efficiency, . . . , and rank 29 represents the lowest efficiency. SE-CRS is super efficiency of constant return to scale efficiency, CE-CRS is cross efficiency of constant return to scale efficiency, Disc-VRS is discriminant analysis of variable return to scale efficiency

Appendix 5: Correlations between efficiency models—Pearson and Spearman(rank)

Pearson[b]\Spearman	SE-CRS	CE-CRS	SE-CRS[a]	CE-CRS[a]	LDA-VRS[a]
SE-CRS		0.6507	0.8880	0.6804	0.4934
CE-CRS	0.8551		0.6129	0.8674	0.5763
SE-CRS[a]	0.6847	0.8802		0.8079	0.3607
CE-CRS[a]	0.6472	0.8674	0.9768		0.5072
Disc-VRS[a]	0.5655	0.5068	0.5014	0.5280	

[a]The case with 1 input
[b]Pearson is above the diagonal

Appendix 6: Data of other explanatory variables[a] Zi by OECD country

	Z1 Internal Students	Z2 GNI	Z3 HDI	Z4 Benefit/cost	Z5 Eng	Z6 Europe	Z7 Z1 × Z5	Z8 Compet.
Australia	21.478	44,097	0.938	4.9062	1	0	21.478	78.7
Austria	17.186	46,231	0.914	2.7312	0	1	0	76.6
Belgium	8.653	43,821	0.919	4.6744	0	1	0	76.4
Canada	12.917	43,602	0.922	2.4952	1	0	12.917	79.6
Chile	0.3800	21,972	0.847	4.1961	0	0	0	70.5
Czech Republic	12.543	31,597	0.891	2.5068	0	1	0	70.9
Denmark	10.757	48,836	0.930	1.6981	0	1	0	81.2
Finland	8.178	41,779	0.925	1.9563	0	1	0	80.2
France	10.195	40,511	0.891	2.6793	0	1	0	78.8
Germany	8.373	46,946	0.939	3.0183	0	1	0	81.8
Hungary	9.974	27,144	0.845	3.4657	0	1	0	65.1
Ireland	8.880	55,660	0.942	7.2928	0	1	0	75.1
Israel	2.883	33,650	0.906	5.3324	0	0	0	76.7
Italy	5.311	36,141	0.883	4.4484	0	1	0	71.5
Korea	2.257	36,757	0.906	2.1445	0	0	0	79.6
Latvia	7.393	26,301	0.854	3.0048	0	1	0	67.0
Luxembourg	46.727	65,543	0.909	2.5756	0	1	0	77.0
Netherlands	10.9987	50,013	0.933	4.8476	0	1	0	82.4
New Zealand	19.609	35,108	0.921	2.7436	1	0	19.609	76.7
Norway	3.1527	68,059	0.954	1.5062	0	1	0	78.1
Poland	4.124	27,626	0.872	2.7375	0	1	0	68.9
Portugal	6.397	27,935	0.850	4.5595	0	1	0	70.4
Slovak Republic	6.898	30,672	0.857	2.2580	0	1	0	66.8
Slovenia	3.884	32,143	0.902	3.7700	0	1	0	70.2
Spain	3.230	35,041	0.893	2.6821	0	1	0	75.3
Switzerland	17.753	59,375	0.946	1.2984	0	1	0	82.3
Turkey	1.501	24,905	0.806	5.1289	0	0	0	62.1
UK	17.917	39,507	0.920	3.9118	1	1	17.917	81.2
USA	5.180	56,140	0.920	4.6347	1	0	5.1797	83.7

[a]Z5—1 for English native speaking, and 0 otherwise, Z6—1 for a European country, Z8—Global Competitiveness Index 4.0

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