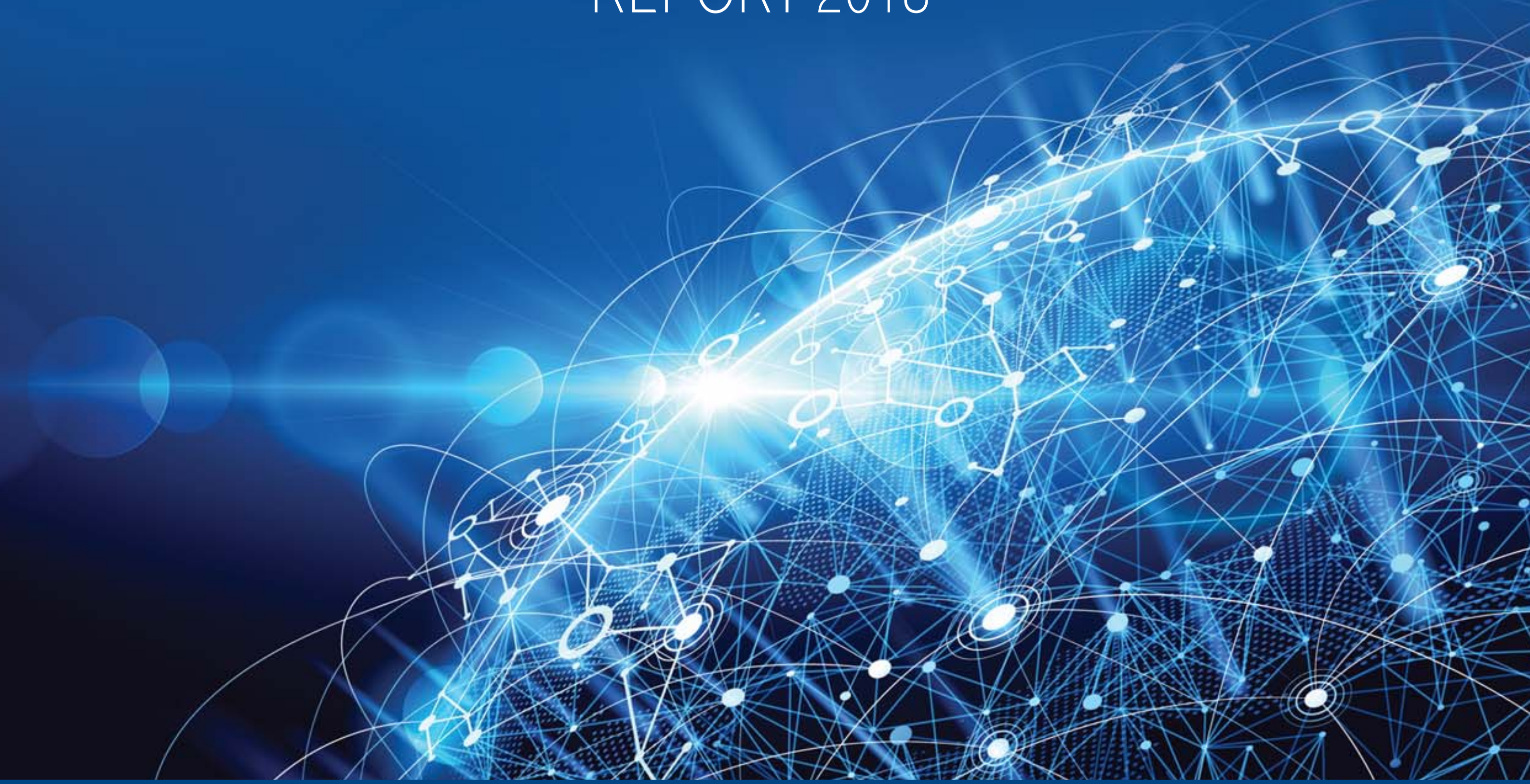
New Approaches to Design and Collection of Data for Subject and Discipline Rankings

ENGINEERING and TECHNOLOGY

REPORT 2018



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IREG Observatory on Academic Ranking and Excellence

IREG Ranking Seminar in Bremen, 15 May 2017

IREG Observatory on Academic Ranking and Excellence

IREG Report: Engineering & Technology Rankings

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Executive Summary

Engineering is a vital discipline in today's knowledge society due to its role in innovating novel technologies to address challenging problems through creative utilization of scientific knowledge. Therefore, educating the next generation of competent and creative engineers is a critical concern for higher education institutions. In a highly globalized knowledge economy and increasingly internationalized educational landscape, comparative evaluations of engineering programs have become a necessity for multiple stakeholders in engineering practice including businesses, researchers, educators, policy makers, administrators and most importantly students and their families.

In an effort to cater to these needs, the IREG Observatory on Academic Ranking and Excellence has launched a project on the "New Approaches to Design and Collection of Data for Subject and Discipline Rankings: Engineering and Technology" and have organized a series of seminars bringing together key stakeholders in this domain to discuss and identify methods to carry out inform comparative analysis of engineering programs at the national, regional and global levels.

This report presents a summary of the main points raised during the discussions, which are geared towards identifying the outline of an engineering ranking that will aim to address the needs of various stakeholders in engineering education and practice.

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Abbreviations

ARWU	Academic Ranking of World Class Universities
CPP	Citations per publication
HEI	Higher Education Institution
H-index	Hersh Index
IREG	IREG Observatory on Academic Ranking and Excellence
NTU	National Taiwan University Ranking
QS	Quaccarelli & Symonds Ranking
THE	Times Higher Education Ranking
URAP	University Ranking by Academic Performance

Contents

Background

of the IREG sponsored project on "New Approaches to Design and Collection of Data for Subject and Discipline Rankings: Engineering and Technology"

IREG Forum in Aalborg (University of Aalborg, 11-12 June 2015) provided a closer look at "subject and discipline rankings" which are currently constructed by major providers of academic rankings in such academic disciplines as *engineering, medicine* and *humanities* and *social sciences*. It has identified similarities but also substantial differences between various academic disciplines, which needs to be taken into consideration when assessing a quality of research and study programs. It has [or should have] consequences for methodology and collection of date used in university rankings.

A prevailing number of international and national rankings produce rankings by discipline as well as study programmes. However, they are most often derived products originator ranking, and what we can observe illustrates the value and limitations of this approach: special schools are better highlighted but many missions and activities that are structuring for these institutions are not taken into account satisfactorily handle. This conceptual shortcoming is clearly noted in case of present "subject ranking" in engineering and technology.

This results in distortions that ultimately are harmful to the diversity of institutions and the development of these disciplines. Consequently;

- specialized institution whose activity is excellent risks that its performance is not properly evaluated by rankings;
- comprehensive universities might be tempted to focus on academic disciplines, which have a "higher quotation" in certain rankings.

This is a general context in which this initiative has been launched. Its main objective is to have a coherent discussion based on commissioned papers allowing formulation of new set of measurements as well as recommendations for data collection and rankings in engineering and technology. A starting point of the project is a comparative analysis and mapping of existing indicators for engineering and technology.

Waldemar Siwinski, President of the Perspektywy Education Foundation (Poland), Vice President of the IREG Observatory was entrusted with the project coordination.

Introduction

Scientists discover the world that exists; engineers create the world that never was.
(T. Von Kármán)

Engineering is a vital discipline in the knowledge society due to its role in innovating novel technologies and solutions to address challenging problems through creative utilization of insights developed by relevant scientific disciplines. Therefore, educating the next generation of competent and creative engineers is a critical concern for higher education institutions (HEI). Engineering is a specialty discipline for HEIs that require significant investments in educational and research infrastructure, careful curricular planning, as well as strong connections and partnerships with the industry. Identifying factors that contribute to the success and impact of engineering programs is an important concern in engineering education. Carefully designed ranking systems with relevant indicators for engineering programs can serve this important need by allowing systematic comparisons across universities offering engineering programs at both national and international levels.

The IREG Working Group on Engineering Rankings includes representatives from the academia, industry, professional associations, accreditation agencies as well as ranking publishers, which covers the viewpoints of several key stakeholders involved with the engineering profession. The group's main goal is to identify a comprehensive list of indicators to inform the design of a system for ranking the engineering institutions in the world. To that end, meetings were held in Bremen, Germany, and Moscow, Russia, and Warsaw, Poland where the group members met face to face to discuss and identify relevant indicators that will serve as a blueprint for a comprehensive, informative and relevant ranking of engineering programs at a global scale.

This report summarizes the workshop participants' views towards what makes engineering programs distinctive at a global level. This is followed by a comprehensive review of some of the existing engineering rankings published by well-known global and national ranking publishers. The goal of the review is to identify the current state of the art in engineering rankings, and to perform a comparison among rankings in terms of their indicators and results. Next, the pros and cons of other potential data sources that can be employed for the development of more informative engineering rankings will be discussed. The report will conclude with an extended table summarizing the key qualities of an engineering program voiced by the stakeholders, possible indicators that could be used to quantify some relevant aspects of those qualities, and possible data sources.

Stakeholders' Perspectives on Excellence in Engineering

Any serious initiative that aim towards ranking higher education institutions should keep in mind the information needs of various stakeholders while identifying and justifying specific ranking indicators. Therefore, an ambitious initiative such as laying out the methodological blueprint of a international ranking of engineering programs should begin with a careful analysis of the perspectives of the stakeholders to identify the key institutional attributes and qualities that bring excellence to an engineering program. To that end, we will first summarize some of the key points made during the IREG seminars by the representatives of different stakeholders regarding engineering education and practice.

Three project seminars were organized:

Seminar in Bremen (organized by IREG Observatory together with University of Bremen and Airbus Company), 15 May 2017.

Seminar in Moscow (organized by IREG Observatory together with National Research Nuclear University "MEPhI" and ROSATOM Company), 30 November - 1 December 2017.

Seminar in Warsaw (organized by IREG Observatory together with National Research Nuclear University "MEPhI", Perspektywy Education Foundation and Foundation for the Development of the Education System "FRSE"), 16 April 2018.

Seminar in Bremen was organized at the invitation of **Axel Herrmann**, Professor for Production Technology at the University of Bremen, and a Director and Chairman of Faserinstitut Bremen e.V. (FIBRE), CEO at the Composite Technology Center Stade (Germany), a company of the **AIRBUS Group**. Prof. Herrmann chaired the seminar and took active part in discussion and formulating a next steps of IREG Engineering Ranking project.

During the seminar the business perspective was articulated by **Christian Flöter**, who is the head of Center of Competence People Resourcing at Airbus, a major company in the global aerospace industry. The recruitment strategy of Airbus emphasizes values such as excellence in technical knowledge as well as teamwork and exposure to a multi-cultural work environment. The ideal situation can be summarized by a T model where a successful engineer has a balanced profile between depth and breadth, where depth refers to the level of engineering knowledge in a specific functional area, discipline or specialty, and breadth refers to the ability to work outside of that core area and relate to other domains of expertise. The challenges to be met in the future requires insights from multiple engineering as well as social and physical science disciplines. Moreover, such insights need to be deployed and communicated in a fast and flexible manner to meet the challenges in an exponentially changing world. The increasingly interdisciplinary nature of the work conducted by companies such as Airbus brings other desirable recruitment profiles such as Pi or Comb models, where an engineer demonstrates depth of knowledge in more than one specialty area. Finally, engineers are expected to effectively function as a team player in a multi-cultural, global workplace.

Given all the above, leading engineering companies such as Airbus consider the following features of engineering programs as key indicators of success:

- Graduates with excellent depth of knowledge in the specialized area. A strong base of knowledge and skills that will enable prospective engineers to work on current and future challenges.
- Initiatives to foster the breadth of knowledge by helping prospective engineers to develop a generalist view towards other specialty areas in engineering as well as key relevant domains such as basic sciences, business, economics and communication.
- Fostering a multicultural learning environment that encourages the development of leadership skills and team work.
- Focused cooperation with industrial partners, as exemplified by programs developed to cater to the needs of the industry, and the existence of joint research projects.
- Availability of special lifelong learning programs for the industry that help companies to keep up to date, beyond what training providers offer.
- Availability of strategic recruitment support policies including effective utilization of career services and alumni networks (e.g. administration of CV handbooks for best students etc.)

Professional communities play a significant role in the establishment of engineering practice in society. **Dirk Bochar**, Secretary General of the European Federation of National Engineering Associations (FEANI) represented the perspective of engineering professionals in the IREG workshop. FEANI is an umbrella organization that brings together professional communities situated in 34 countries mainly in Europe. As part of its mission, FEANI aims to unify the voice of engineering professionals in Europe, to affirm and develop their professional identity, to facilitate the mutual recognition of engineering qualifications in Europe, and to strengthen the position, role and responsibility of engineers in society. FEANI's EUR ING professional title is a key instrument for establishing mutual recognition of engineering degrees and facilitating the mobility of engineering professionals in EU. Inclusion criteria requires candidates to have an engineering degree from an approved program as well as evidence for industrial experience, which covers a minimum total duration of seven years of academic study and professional employment. Since the approval process requires verification of the applicant's credentials by both local and regional professional organizations, the process produces a valid record of an engineers' educational background and the state of his/her career. The FEANI register database currently includes information about more than 33.300 engineers in 34 countries who are entitled to use the EUR ING title. The database also includes information about 1000 higher education institutions offering a total of 14.400 engineering programs. Institutions accredited by EUR ACE authorized accreditation bodies are automatically included in this database. There is an ongoing effort to merge the ENAEE EUR-ACE accreditation label database and the FEANI Index, which will be an important resource for ranking purposes. As a founding member of the World Federation of Engineering Organizations, FEANI is playing a key role in the global engineering community, which opens the possibility to organize a database like the FEANI Index at a global scale. Such an initiative will play a key role in obtaining quality institutional data that is crucial for a global engineering ranking. The database enables not only to identify the names and the number of registered alumni of an institution, but also to track each degree holder's employment record and their alma mater in a valid manner.

Accreditation is a key aspect of quality assurance in engineering education. **Bernard Remaud**, president of the The European Network for the Accreditation of Engineering Education (ENAEE) represented the perspective of accreditation organizations during the workshop. Prof. Remaud emphasized that accreditation processes and rankings pursue different goals, so they may emphasize different attributes of higher education institutions. Rankings tend to emphasize excellence in research output as captured by a relatively small number of output indicators without individually evaluating engineering degree granting programs. Instead, the accreditation process emphasizes program quality, where the focus is on promoting awareness regarding education, quality assessment and improvement. In particular, ENEEA aims to enhance the overall quality of engineering education in Europe, to facilitate the development of national quality assurance (QA) systems for engineering education, and to foster academic and professional mobility between countries with a wide diversity of education systems and professional regulations. The main goal of these efforts is to arrive at an agreed upon characterization of what an engineering graduate is supposed to know and be able to do, and to establish requirements and goals for the educational system to equip the engineering graduates with the necessary knowledge and skills to fulfill the expected outcomes. The accreditation process aims to increase the institutions' awareness with regards to agreed upon principles of quality assurance, and to encourage them to reflect on their strengths and weaknesses. Such evaluations are critical for further improvement of the quality of engineering education. The accreditation process treats each engineering program separately at the Bachelor's and Master's levels only, and covers specific durations of time where the process needs to be renewed periodically to check whether the institution is keeping up with the expected quality standards. ENEAA currently maintains the EUR-ACE® Database, which includes information about the accredited Engineering Degree programmes that have been awarded the EUR-ACE® label.

Since the ultimate goal of the IREG Observatory study is to develop the blueprint of an international ranking of engineering institutions, ranking publishers were also featured in the workshop. **Waldemar Siwiński** who hosted the seminar on behalf of IREG, also represented the Perspektywy Ranking, and presented the methodology of their new ranking of Polish engineering programs. Moreover, **Murat Perit Çakır from** the University Ranking by Academic Performance (URAP) team presented an overview of the indicators employed by existing global and national rankings that are specialized to engineering. A more detailed review of these indicators will be provided in the next section.

During the seminar several bibliometric indicators were proposed and discussed for a global ranking of engineering programs by **Prof. Oleg Nagornov** and **Prof. Sergey Kireev** of the National Research Nuclear University "MEPhI". In particular, the following indicators were suggested for a preliminary ranking; faculty to student ratio, industry income per faculty, share of publications with academic and corporate affiliations, field-weighted views impact, share of international faculty, share of international students, share of publications with international co-authorship, and share of graduates who has completed a certification at an international corporation. All of these indicators except the field normalized access information are employed by existing engineering rankings, so they will be described and categorized in a subsequent section dedicated to currently used indicators. However, none of the existing engineering rankings use the field normalized publication access information, which is provided by the SciVal service based on publication access information logged by Elsevier's Scopus and ScienceDirect products. As it was discussed during the meeting, the number of views and downloads can be quite suggestive in terms of whether a publication is attracting interest from other researchers active in that domain. Attracting citations naturally take a longer duration of time, so access statistics can be a useful complement to measure the immediate impact and current relevance of publications from an engineering institution. One can also consider the degree to which such views translate into citation counts as another quality indicator. Another important point stressed was the need for country normalization due to variations in economic parameters (e.g. unemployment rate, purchase power parity). The level of the industry is shaped by the economic parameters, which also shapes the industrial impact a university can generate in its local setting.

It has become increasingly apparent that due to its specific nature, engineering education cannot be correctly assessed solely by the tools normally employed by university rankings. IREG Observatory, it turns out, is not alone in its approach to classification of engineering education. Recently, there have been studies that shed new light on the quality of engineering education and, indirectly, support the path taken by IREG Engineering Ranking Group.

At the Moscow Seminar Prof. **Greet Langie** spoke about efforts taken by the European Society for Engineering Education (SEFI) to identify and promote new trends in engineering education. What the current advanced technology requires from graduates of engineering can no longer be achieved through the traditional teaching methods (chalk and talk). The future of engineering education SEFI see in new teaching methods such as:

- Project-assisted learning
- Project-based learning
- Design based learning
- CDIO concept (conceive – design – implement – operate)

The common characteristic of all these methods is that they go away from the traditional teacher oriented process of education in the direction of student oriented education.

This kind of education should produce well educated engineers that**:**

- are accustomed to technological change since they will work in an unknowable future
- have 21st century skills since they are the drivers for this accelerated change (curiosity, openness, entrepreneurial mindset, interdisciplinarity, global awareness)
- have I-profiles (influential personality) or T-profiles (depth of knowledge and ability to work with others), since industry needs different professional roles in this multidiverse society.

Changes in the methods of education call for a new generation of indicators and criteria that can be applied to rankings in the field of Engineering and Technology. These indicators should tell how well engineers are educated and trained to meet the needs of industry and other stakeholders in higher education.

Even closer to the idea behind the IREG Observatory project comes Dr. **Ruth Graham** in a recent Massachusetts Institute of Technology (MIT) report *"The global state of the art of engineering education".* The study is a result of examination of engineering programs in several leading university in different parts of the world such as Singapore, United Kingdom, Australia, Netherlands, Denmark, Chile, USA and China. The MIT study was in fact a search for "a world-leading program of engineering education at the university". Three groups of indicators of quality in engineering education have been identified.

1. The quality and impact of the graduates measured by such indicators as "career prospects ten years after" or "have the capabilities that industry needs now and in the future"
2. The "value added" to students during their studies , here, however, "we just don't have the quality and breadth of data".
3. The institution's capacity to deliver a world-class education. The following dimensions of institutional capacity were emphasized:
   - leadership and commitment to education – rewarding teaching excellence
   - the educational culture – being innovative and ready to try new things
   - the capacity to influence practice elsewhere – transferability of good practices to other universities

The MIT study identified a number of features that characterizes institutions, leaders in engineering education:

- Students to be engaged with universities research activity
- Extra-curricular activities and experiences available for students
- Opportunities for hands-on experimental learning "problem identification and problem solution"
- Development of students' entrepreneurial capabilities and social responsibility
- Capabilities of online and blended learning
- Partnerships with industry

The findings of the MIT study correspond well with the expectations regarding engineering education of the leading European presented at the IREG Engineering Group Seminar in Warsaw by **Dirk Bochar**, Secretary General of FEANI. Bochar pointed out that present instruments for measuring "Quality" are inadequate, as they:

- Offer limited evidence of what is learned and at what level.
- QA is mainly process oriented not really outcome focused.
- QA is looking backward not forward: lack focus on future needs of society and the graduate.
- Peer reviewing is a doubtful model: in European context peers very often are not well informed about modern methods and approaches regarding LTA. Therefore: reviews often biased.
- Offer limited evidence about the real quality and relevance of degree programs and their performance.

There is a demand for more reliable information about the outcomes of learning in Higher Education that will reflect on the quality of engineering education that should provide knowledge, teach how to apply knowledge and skills, prepare for employability and prepare for civic, social and cultural engagement.

European response to these challenges is project called "Measuring and Comparing Achievements of Learning Outcomes in Higher Education in Europe" (CALOHEE). According to Dirk Bochar, this EU funded project, a part of the TUNING program, provides a very promising framework for the assessment of outcomes of engineer education.

There are several other projects under way that seek new approaches to analyze and measure the effects of interaction between universities and business. **Dr. Pawel Poszytek**, Director of the Foundation for the Development of the Education System (national Erasmus+ agency in Poland) presented project called: *"New indicators measuring the scope and quality of university-business cooperation in technical universities"*.

The project is based on the assumption that innovations created thanks to scientific research and knowledge are the main driving force of the developed economies. They allow for improvement of the existing and design new products and services as well as to diversify the market offer which can boost corporate profits and lower the production costs. Innovations contribute to better adaptation to the requirements and expectations of the market and customers, which translates to raising companies' competitiveness. The growth of innovativeness is attributable not only to universities (with a special stress on technical universities), which provide research results, but predominantly to the private sector. Hence, an efficient combination of enterprises and scientific research environment is a sine qua non condition for the growth of innovativeness and competitiveness in modern economy.

Therefore the Foundation for the Development of the Education System has established the Index of Higher Education - Business Engagement (HEBE Index) in order to: understand how and to what extent universities cooperate with business, illustrate the current situation of university-business cooperation, identify drivers and obstacles to this cooperation, and inspire new policy focus and create recommendations that, in the long run, will allow for boosting the university business cooperation and increase the country's innovativeness. The HEBE Index defines 5 key strands of university-business cooperation, namely: research and development, personnel and student mobility, curriculum development, commercial activities and public engagement. Within each strand a number of indicators is proposed to capture the state of university-business interactions.

From the point of view of technical universities the following indicators are of crucial importance:

- number of joint and commissioned research activities,
- number of academics working temporarily for business,
- number of business representatives working temporarily in the academia,
- number of student placements and internships,
- number of joint study programmes and students enrolled,
- number and value of patents and licenses,
- number and sustainability of spinn offs, spin outs and start ups commercialisation of research results and value of consulting activities.

The above-mentioned indicators can assure accuracy and reliability resulting in a limited possibility to manipulate the indicator value. They can also make the data-collection process relatively easy, provided it is carried out by internal researchers at a given university. The HEBE Index is also easy to decompose and can constitute a valuable tool measuring university-business interactions, with a particular stress on technical universities and their connections to the business world.

The appropriate assessment of the quality of engineering education has become a key issue for global technology based companies – concluded **Andrey Khitrov**, Director General of Employers' Union of Nuclear Industry, Energy and Science of Russia, Chairman of the Board on Professional Qualifications in Nuclear Energy Sphere, ROSATOM. Cooperation between universities and the industry has become of outmost importance here, and it should be reflected in the teaching of engineers and accreditation procedures in the nuclear energy sector.

All the participants of the IREG Engineering Ranking seminars, and specially **Prof. Marek Tukiendorf**, rector of the Opole University of Technology (Poland) and **Prof. Vladimir Zernov**, rector of the New Russian University (Russia) have stressed the importance of practical training for students in the context of the potential criteria and indicator for rankings. **Dr. Wolfgang Lambrecht**, Director of International Office, Chemnitz University of Technology (Germany) spoke about the joint industry and university research clusters and he suggested how indicators related to such research can be included into engineering ranking.

Oleg Solovyev, Editor of Round University Ranking presented suggestions for engineering ranking methodology prepared by his team. In his opinion, the key task is to develop publically available database which might be used by all ranking providers under the supervision of IREG Observatory.

Note: presentations from the IREG Engineering Ranking Group seminars can be found on the website: www.ireg-observatory.org/engineering .

Review of Existing Engineering Rankings

Several global and national ranking systems offer specialized rankings for engineering programs. The following subsections provide an overview of existing engineering rankings in an effort to identify the similarities and differences among them.

Global Engineering Rankings

Global rankings such as QS, THE, ARWU, NTU and URAP provide special field rankings in engineering as well as its specialty subject areas such as chemical, mechanical, and electrical engineering.

QS Engineering Rankings

QS World University Ranking publishes specialized rankings in 42 subject areas[1], 7 of which are related to engineering related subject areas. QS employs 4 criteria, namely academic reputation, employer reputation, citations per paper and h-index of citations for its subject rankings (Table 1). The first two indicators are derived from data collected via reputation surveys, which is specialized for each discipline. The other two criteria are based on publications in the related subject area indexed in the Scopus database. QS employs an adaptive weighting scheme based on the discipline's publication output. Publication-based indicators are computed from the Scopus database through its subject classification. For all engineering rankings reputation based criteria constitutes 70% of the total score, whereas publication based scores account for the remaining 30%. For each engineering subject area, top 50 institutions are ranked individually, whereas the remaining institutions are ranked within bands including 50 institutions (e.g. 51-100, 101-150, 151-200, etc.)

[1] https://www.topuniversities.com/university-rankings-articles/university-subject-rankings/qs-world-university-rankings-subject-methodology

Table 1. The indicators used by QS for the engineering subject area rankings.

QS Engineering Subject Area	**Academic Reputation**	**Employee Reputation**	**Citations per Paper**	**H-Index Citations**	**# of Ranked Institutions**
General Engineering	40%	30%	15%	15%	50 (300)
Chemical Engineering	40%	30%	15%	15%	50 (200)
Civil & Structural Engineering	40%	30%	15%	15%	50 (200)
Computer Science	40%	30%	15%	15%	50 (500)
Electrical Engineering	40%	30%	15%	15%	50 (300)
Mechanical, Aeronautical & Manufacturing Engineering	40%	30%	15%	15%	50 (300)
Mineral & Mining Engineering	50%	20%	15%	15%	50 (100)

ARWU Engineering Rankings

ARWU publishes a general Engineering ranking[2], which uses highly cited researchers in 3 categories (engineering, computer science, materials science), papers indexed in the Science Citation Index Expanded in the subject area Engineering, Percentage of papers published in the top 20% journals in engineering, and total engineering-related research expenditures. Alumni and award criteria are not used for the Engineering ranking, which are applied to other field rankings, such as Medicine and Science. The 25% weight attributed to awards are equally distributed over other engineering related categories. Expenditure information is reported to be available only for US and some Canadian institutions, as the data is obtained from American Society for Engineering Education (http://profiles.asee.org/). For those institutions whose expenditure information is not available, the corresponding weight is distributed evenly over other categories. The last version of the ARWU Engineering Ranking is dated 2016, which has not been updated since.

ARWU also publishes more fine grained subject area rankings, 22 of which are related to engineering (Table 2). In the most recent and expanded edition of the subject area ranking, ARWU identified 52 subject areas based on Web of Science journal categories[3]. Institutions that exceed a threshold for the minimum number of publications in the selected subject area are included in the corresponding ranking. A separate threshold is applied for each subject area due to the differences among them in terms of their publication volumes. Five indicators are used with different weights for each subject area. The number of papers authored by an institution (PUB), category normalized citation impact of

[2] http://www.shanghairanking.com/FieldENG2016.html

[3] http://www.shanghairanking.com/Shanghairanking-Subject Rankings/attachment/Mapping_between_Web_of_Science_categories_and_52_academic_subjects.pdf

those publications (CNCI), the percentage of internationally collaborated papers (IC), the number of papers published in top journals (TOP) and the total number of staff in an institution who had received a significant award in the corresponding subject area (AWARD) constitute the five ranking indicators for the ARWU subject area ranking. For the PUB, CNCI, IC and TOP indicators, only publications of type article that were published in the last 5 years are considered. The bibliometric measures are obtained from the InCites™ service of Clarivate Analytics. The list of top journals in each field is identified through ARWU's Academic Excellence survey, where respondents selected 94 journals in 33 different subject areas as top journals in their fields. For those subject areas that do not have survey input, the journals in the top 20% in terms of their impact factor are considered. The awards carry a non-zero weight for 9 out of the 22 engineering related subject rankings. For those 9 subject areas, the list of significant awards are gathered through ARWU's Academic Excellence survey[4].

Table 2. The indicator weights and the publication thresholds used by ARWU for the engineering subject area rankings.

ARWU Engineering Subject Area	PUB	CNCI	IC	TOP	AWARD	Publication Threshold	# of Ranked Institutions
Energy Science & Engineering	100	100	20	200	-	100	50 (300)
Aerospace Engineering	100	100	20	200	-	25	50 (100)
Computer Science & Engineering	100	100	20	20	180	150	50 (500)
Mechanical Engineering	100	100	20	100	100	50	50 (300)
Electrical & Electronic Engineering	100	100	20	100	100	100	50 (500)
Automation & Control	100	100	20	100	100	100	50 (100)
Biomedical Engineering	100	100	20	100	100	50	50 (300)
Civil Engineering	100	100	20	100	100	50	50 (300)
Chemical Engineering	100	100	20	100	100	100	50 (300)
Materials Science & Engineering	100	100	20	100	100	200	50 (500)
Environmental Science & Eng.	100	100	20	100	100	100	50 (400)
Telecommunication Engineering	100	100	20	100	-	50	50 (200)
Instruments Science & Technology	100	100	20	100	-	50	50 (300)
Nanoscience & Nanotechnology	100	100	20	100	-	100	50 (300)
Water Resources	100	100	20	100	-	50	50 (200)
Food Science & Technology	100	100	20	100	-	50	50 (300)
Biotechnology	100	100	20	100	-	100	50 (300)
Marine/Ocean Engineering	100	100	20	100	-	25	50 (50)
Transportation Science & Technology	100	100	20	100	-	50	50 (100)
Remote Sensing	100	100	20	100	-	50	50 (50)
Mining & Mineral Engineering	100	100	20	100	-	25	50 (50)
Metallurgical Engineering	100	100	20	100	-	50	50 (200)

[4] http://www.shanghairanking.com/subject-survey/awards.html

THE Engineering Ranking

Times Higher Education (THE) Ranking also publishes subject rankings[5], 6 of which are related to engineering disciplines. THE ranking includes those institutions that have at least 100 papers published in engineering related journals indexed in Scopus in the last 5 years. The same indicators are employed for the general ranking, which are summarized in Table 3 together with corresponding weights. THE is the only international ranking that uses a teaching dimension in their engineering ranking, which is based on a combination of the reputation survey (15%), staff to student ratio (4.5%), doctorate to bachelor's ratio (2.25%), doctorates awarded to academic staff ratio (6%) and institutional income (2.25%). The research dimension is composed of the reputation survey (18%), research income (6%) and research productivity (6%) indicators, where productivity refers to the publication output in the related engineering discipline. International outlook includes international to domestic student ratio (2.5%), international to domestic staff ratio (2.5%) and the number of internationally co-authored papers (2.5%).

Table 3. The indicators used by THE for the engineering subject area rankings.

THE Engineering Rankings	Teaching	Research	Citations	International Outlook	Industry Income	# of Ranked Institutions
General Engineering	30%	30%	27.5%	7.5%	5%	100 (500)
Chemical Engineering	30%	30%	27.5%	7.5%	5%	100 (500)
Civil Engineering	30%	30%	27.5%	7.5%	5%	100 (500)
Computer Science	30%	30%	27.5%	7.5%	5%	100 (300)
Electrical & Electronic Engineering	30%	30%	27.5%	7.5%	5%	100 (500)
Mechanical & Aerospace Engineering	30%	30%	27.5%	7.5%	5%	100 (500)

URAP Engineering Ranking

URAP (University Ranking by Academic Performance) ranking published 41 subject rankings in its most recent release[6], 9 of which are related to engineering disciplines. The subject taxonomy used is based on the implementation the Australian Research Council's subject classification in Clarivate Analytics InCites™. URAP uses bibliometric indicators only, where the number of articles, citations and articles with international co-authors constitute 55% of the ranking (Table 4). The remaining two indicators consider the normalized counts of articles and citations with respect to the world average in

[5] https://www.timeshighereducation.com/world-university-rankings/subject-ranking-2016-2017-engineering-and-technology-methodology
[6] http://www.urapcenter.org/2016/fields.php

the corresponding engineering discipline. The number of institutions included in each subject ranking varies from 100 to 1000 due to the differences in the coverage of specific engineering disciplines in InCites™, which is based on Web of Science database.

Table 4. The indicators used by URAP for the engineering subject area rankings.

URAP Engineering Rankings	Article	Citation	International Collaboration	Article Impact Total	Citation Impact Total	# of Ranked Institutions
Engineering	25%	20%	10%	20%	25%	1000
Chemical Eng.	25%	20%	10%	20%	25%	400
Civil Eng.	25%	20%	10%	20%	25%	400
Information & Computer Science	25%	20%	10%	20%	25%	600
Electrical & Electronics Eng.	25%	20%	10%	20%	25%	400
Environmental Eng.	25%	20%	10%	20%	25%	100
Food Eng.	25%	20%	10%	20%	25%	100
Materials Eng.	25%	20%	10%	20%	25%	400
Mechanical Eng.	25%	20%	10%	20%	25%	400

The 2018 edition of the URAP subject area ranking will increase the number of engineering related subject rankings to 14. Moreover, the article indicator will be updated to include only those articles that were published in journals in the first three quartiles in terms of their impact factors in the corresponding field. A new indicator taking into account other publication types besides articles will also be added to the new rankings, which will be announce in June 2018.

NTU Engineering Ranking

National Taiwan University (NTU) Ranking also publishes a general Engineering ranking as well as subject rankings for Chemical, Civil, Computer, Electrical, Materials and Mechanical Engineering (Table 5). The same bibliometric indicators for the NTU global ranking are used for the engineering rankings as well, but the measures are filtered for the corresponding subject area. The NTU rankings are based on Web of Science data. The number of unique institutions ranked in each engineering ranking is around 300.

Table 5. The indicators used by NTU for the engineering subject area rankings.

NTU Engineering Rankings	11 Years Articles	Current Articles	11 Years Cites	Current Cites	Ave. Cites	H-Index	HiCi Papers	Hi-Impact Journal Articles	# of Ranked Institutions
General Engineering	10%	15%	15%	10%	10%	10%	15%	15%	293
Chemical Eng.	10%	15%	15%	10%	10%	10%	15%	15%	296
Civil Eng.	10%	15%	15%	10%	10%	10%	15%	15%	294
Computer Eng.	10%	15%	15%	10%	10%	10%	15%	15%	294
Electrical Eng.	10%	15%	15%	10%	10%	10%	15%	15%	299
Materials Eng.	10%	15%	15%	10%	10%	10%	15%	15%	294
Mechanical Eng.	10%	15%	15%	10%	10%	10%	15%	15%	298

U.S. News Global Engineering Ranking

As of 2018, US News has also started publishing a global subject ranking focusing on engineering. The ranking is based on several indicators including global and regional research reputation (%12.5 each), publications (%17.5), normalized citation impact (%7.5), total citations (%12.5), the number and percentage of publications in top %10 in terms of citations accrued (%12.5 and %5 respectively), the number and percentage of publications in top %1 in terms of citations accrued (%5 and %5 respectively), the number and percentage of papers published through international collaboration (%5 and %5 respectively).

The U.S: News engineering ranking is based on publications covering a number of engineering disciplines, ranging rom aerospace, mechanical, electrical and civil engineering to nuclear energy, applied artificial intelligence and robotics, publications within this category focus on designing, building and using structures, machines and systems, as captured by Web of Science subject categories. The bibliometic data is obtained through InCites for the year range 2011-2015. Universities that have a published paper count of 250 or more in the 2011-2015 time period in engineering subjects were included in the ranking. The US News Engineering Ranking covers the top 600 institutions. No additional engineering related subject area rankings are provided by US News.

U-Multirank Science & Technology Rankings

U-Multirank follows a different approach to university rankings by assigning ordinal scores for universities across several dimensions to aid students and parents to perform comparative analysis of higher education institutions. Apart from providing interactive interfaces for personalize analysis and comparison of institutions, U-Multirank also offers ready-made rankings that cover subject areas related to engineering, such as chemical engineering, civil engineering, electrical engineering, computer science, mechanical engineering and production / industrial engineering. The ranking indicators are grouped under four main dimensions, namely Teaching, Research, Knowledge Transfer and International Outlook. Each institution is assigned an ordinal score of 1-5 and the indicators are not assigned explicit weights. Since some of the indicators related to teaching and PhD students require input from the institutions, the coverage of U-Multirank engineering subject rankings are smaller than other international rankings.

Table 6. The indicators used by U-Multirank for the engineering subject area rankings.

	Teaching		Research			Knowledge Transfer		International Orientation		
U-Multirank Engineering Rankings	**Student to Staff Ratio**	**Academic Staff with PhD**	**Doctorate Productivity**	**Citation Rate**	**Top Cited Publications**	**Co-publications with Industry**	**Publications Cited in Patents**	**International PhD Degrees**	**International Joint Publications**	**Number of Ranked Institutions**
Chemical Eng.	11%	11%	11%	11%	11%	11%	11%	11%	11%	77
Civil Eng.	11%	11%	11%	11%	11%	11%	11%	11%	11%	80
Computer Eng.	11%	11%	11%	11%	11%	11%	11%	11%	11%	104
Electrical Eng.	11%	11%	11%	11%	11%	11%	11%	11%	11%	113
Mechanical Eng.	11%	11%	11%	11%	11%	11%	11%	11%	11%	102
Production/Industrial Eng.	11%	11%	11%	11%	11%	11%	11%	11%	11%	16

Among other leading global university rankings, Webometrics and The Leiden Ranking do not publish any subject rankings specialized for engineering disciplines as of 2018.

National Engineering Rankings

In addition to international rankings, there are also national rankings that publish specialized tables for the local engineering schools. The following sample of national rankings include those engineering rankings regularly published in USA, Canada, UK, France, and Poland.

USA: U.S. News Engineering Ranking

One of the oldest and widely known national rankings, U.S. News publish two separate rankings for undergraduate and graduate engineering programs in the U.S. Undergraduate programs that are accredited by ABET are ranked based on peer assessment ratings provided by the deans and senior faculty members[7]. In other words, ABET accredited undergraduate engineering programs are ranked in terms of their reputation among engineering faculty. Specialty engineering subject rankings for civil, chemical, mechanical and electrical engineering are provided based on the nominations of the 10 best engineering programs in specialty engineering areas. For the graduate engineering schools ranking in the US, several indicators are employed, namely quality assessment (40%) based on peer assessment (25%) and recruiter assessment (15%), student selectivity (10%) based on mean graduate record examination (GRE) quantitative test scores and the acceptance rate, faculty resources (25%) based on student-faculty ratio, percentage of faculty in the National Academy of Engineering and doctoral degrees awarded, research activity (25%) based on total research expenditure and average research expenditure per faculty[8].

Canada: Maclean's Engineering Ranking

Maclean publishes a ranking of engineering programs in Canada, which is based on 5 indicators, namely field weighted citation impact (35%), fractional publications (10%), fractional citations (10%), program reputation (35%) and research reputation (10%)[9]. The reputation survey is conducted by Maclean's, whereas the bibliometric data is obtained from the Scopus database.

UK: The Complete University Guide Engineering Rankings

In the UK, The Complete University Guide publishes subject rankings, including General Engineering, Chemical Engineering, Computer Science, Electrical & Electronic Engineering, and Mechanical Engineering. The subject rankings are based on 4 dimensions, namely entry standards, student satisfaction, research quality, research intensity and graduate prospects. Entry standards is a measure of the average success of the incoming class of that program as measured through standardized tests taken by the students prior to admission. Student satisfaction data is based on the national student survey conducted in UK. Research quality is based on an ordinal scale of 1-4 determined by the

[7] http://www.usnews.com/education/best-colleges/articles/undergraduate-engineering-programs-methodology

[8] http://www.usnews.com/education/best-graduate-schools/articles/engineering-schools-methodology

[9] http://www.macleans.ca/education/the-top-20-program-rankings-in-10-subject-areas/

category assigned to each institution by the UK Research Excellence Framework. Research intensity refers to the ratio of the staff covered in the excellence framework to the total number of staff at the program. Graduate prospects is based on the number of graduates who take up employment or further study divided by the total number of graduates.

France: L'Etudiant General Ranking of Engineering Schools

In France, L'Etudiant magazine[10] publishes an annual ranking of French engineering schools, which employs several indicators based on data obtained through surveys administered to universities and students, as well as on certified data provided by the Conference of Deans of French Schools of Engineering (CDEFI) and the French accreditation agency Commission des titres d'ingénieurs (CTI). The current ranking includes 168 engineering schools in France that are authorized to issue engineering degrees. The 12 indicators used in the ranking are grouped under 3 broad categories, namely academic excellence, business connections, and international outlook. Although the ranking system includes several additional indicators, they were not reflected in the ranking due to challenges in collecting the data from the institutions. The complete list of indicators are presented below under each theme since L'Etudiant is the most comprehensive engineering ranking in terms of the diversity of the indicators used.

Academic excellence was comprised of the following indicators; the duration of Commission des titres d'ingénieurs (CTI) accreditation (max 6 years), the average grade points of freshmen class entering the engineering program (either from year 1 or 3 depending on the program), number of students per teacher, the percentage of teaching and research faculty, number of PhD students funded and supervised by the engineering school, the number of HDR faculty (i.e. research authorization, highest degree of French diplomas).

Business connections were evaluated with respect to the following indicators; percentage and the number of students enrolled in apprenticeship at companies, number of instructors from the industry, the minimum duration of internships, the existence of industry chairs in the program that facilitate industry funded research in the program, the number of companies and SMEs that participated in business forums hosted by the university (which shows the school's ability to mobilize large and small companies), the number of graduates of the school obtained through the school's alumni network, the number of former members of the engineering program enrolled in the LinkedIn page of the school, and the number of graduates who started up new businesses.

International outlook featured the following indicators; percentage of international students, whether the school has a campus abroad, the required level of English proficiency, the existence of a requirement for learning a second language, the minimum duration spent abroad for apprenticeship,

[10] http://www.letudiant.fr/palmares/liste-profils/palmares-des-ecoles-d-ingenieurs/palmares-des-ecoles-d-ingenieurs-notre-methodologie/home.html

academic exchange for students as well as for alumni, number of students enrolled in dual degree programs with an international partner institution, percentage of dual degree graduates, and international reputation which is based on the ranking of the institution in international rankings published by QS, THE, ARWU and Webometrics.

L'Etudiant ranking also offers several additional indicators. The salary range of the new graduates, the number of graduates who were employed abroad, the share of the institution's graduates in engineering sectors such as energy, transport, information technology etc., number of students who joined the school at the beginning of the school year, number of students who entered the engineering cycle at the beginning of the school year after completing their integrated preparation, number of students who joined the school in 2016 after a pre-school class, number of pupils enrolled in parallel admissions at the beginning of the 2016 academic year, percentage of students enrolled in parallel admissions at the beginning of the 2016 academic year, number of students holding a BTS (senior technician 's certificate) or who have completed one year of preparatory ATS (higher technician adaptation) course, number of students with a DUT (university degree in technology) integrated at the beginning of the 2016 academic year, number of students with a bachelor's degree or a master's degree matriculated in the 2016 academic year, proportion of baccalauréat holders in the 1st year and 3rd year for the baccalauréat schools, percentage of graduates holding STI2D baccalaureat in 1st year and 3rd year for baccalaureate schools, share of graduates holding a baccalaureate other than the S and STI2D bins, integrated in the first year and the third year for the baccalaureate schools, number of students enrolled in the ES baccalaureate at the start of the 2016 academic year, number of students enrolled in the baccalaureate L, number of students enrolled in the STL baccalaureate, number of students holding a bachelor's degree in agronomy and life sciences (STAV), number of students with a STD2A, STMG or ST2S baccalaureate integrated in the 2016 academic year, number of students holding a vocational baccalaureate in the incoming class of 2016.

These parameters are highly localized to the peculiarities of the French educational system, so may not be easily applicable to other countries. Moreover, since the institutions were requested to provide this body of information through a survey and most could not comply, the majority of the indicators listed above could not be reflected on the final ranking as well.

Poland: Perspektywy Ranking by Subject in Engineering

Beginning in 2016, Perspektywy has begun to publish a subject ranking specialized in engineering programs in Poland. The most recent edition of the Perspektywy Engineering Ranking covers 21 engineering subject areas, namely Automation and Robotics, Architecture and Urban Planning, Biomedical Engineering, Biotechnology, Chemical and Process Engineering, Chemical Technology, Civil Engineering, Computer Science, Electrotechnics, Electronics and Telecommunication, Environmental Engineering, Geodesy and Cartography, Logistics, Management and Production Engineering, Material Science, Mechanical Engineering, Mechatronics, Mining and Geology, Power Engineering, Technical Physics, and Transport. Perspektywy engineering related subject rankings are based on 12 indicators grouped under 6 themes, namely prestige, alumni situation on the job market, academic potential, scientific efficiency, didactic potential, and innovation. The weights assigned to the indicators are decided annually by the Ranking Board that consists of a group of higher education experts.

Under the theme prestige, the number of mentions received by each institution in an annual survey administered to the academic staff in Poland is considered (%12). Alumni situation on the job market is assessed through the results of a survey administered by the Polish Ministry of Science and Higher Education, which provides data on the employment rate of graduates in each subject as well as the rates of their earnings (%15). Academic potential is measured in three dimensions based on the rating given to the university by the Scientific Units Evaluation Committee appointed by the Ministry of Science and Higher Education (%10), the number of subject related programs in which the university offers PhD programs (%5), and the number of awarded PhD and habilitated doctorate degrees (%2). Under the theme scientific efficiency bibliometric indicators in the related subject area such as the number of publications (%8), percent of cited publications (%8) and field weighted citation impact (%4) in the last 3 years are considered, which are obtained from Scopus and SciVal databases. Didactic potential is evaluated based on the ratio of faculty with PhD or PhD with habilitation degrees to the number of full/part-time students (%5), the quality of students admitted to the university (%15), and the international accreditations (e.g. ABETi EUR-ACE, RIBA, ECTN) and/or any distinguishing titles given by the Polish Accreditation Comission (%8). Finally, the innovation dimension assesses the institutions based on the number of patents and protection rights they obtained (%8).

Comparison of Existing Global Engineering Rankings

Our review of existing rankings suggests that there are both similarities and differences among existing engineering rankings in terms of their methodologies. In an effort to analyze the level of similarity among existing global rankings, we compared the top 50 general engineering rankings published by ARWU, THE, URAP and NTU. QS is not included in this analysis since QS does not publish a general engineering ranking. Table 6 below displays the rankings assigned by each system to the universities in their top 50. The table is stratified in terms of the number of times a university appeared in all 4 rankings. For instance, MIT is ranked by all 4 rankings, whereas King Abdulaziz University is ranked by ARWU only. Within each stratum, the universities are sorted in terms of the sum of their ranks in descending order.

Table 6. A rank comparison of the top 50 lists of 4 global engineering rankings

University	ARWU Rank	NTU Rank	THE Rank	URAP Rank	US News
Stanford University	2	10	1	15	13
Massachusetts Institute of Technology (MIT)	1	5	4	5	3
University of Cambridge	19	24	5	19	42
National University of Singapore	6	3	8	4	2
Swiss Federal Institute of Technology Zurich	27	26	9	12	12
Imperial College London	7	18	10	10	9
Georgia Institute of Technology	12	9	11	11	14
University of California, Berkeley	8	7	13	8	5
Swiss Federal Institute of Technology Lausanne	11	15	14	22	18
University of Illinois Urbana-Champaign	13	22	14	31	19
Nanyang Technological University	2	2	16	2	4
University of Michigan, Ann Arbor	15	25	17	18	15
Tsinghua University	4	1	22	1	1
Purdue University - West Lafayette	18	40	25	42	40
University of Texas, Austin	10	16	28	21	34
University of Science & Technology of China	28	14	39	16	31
Shanghai Jiao Tong University	16	6	41	6	11
Zhejiang University	14	8	50	3	7
Peking University		20	7	20	23
Harvard University	37	18		9	41
Delft University of Technology		34	18	29	20
Korea Advanced Inst. of Sci. & Tech. (KAIST)		27	27	30	45
University of Toronto	50	43	29	41	
University of California, San Diego	23	49	33		28
Fudan University	41	37	47	27	
Harbin Institute of Technology	9	4		7	6
Xian Jiao Tong University	21	17		33	36
South China University of Technology	22	31		24	46

City University of Hong Kong	24	12		45	16
Southeast University	20	28		40	27
Technical University of Denmark	33	36		26	24
University of California, Los Angeles	29	33		43	44
University of New South Wales	42	46		39	25
Princeton University	32		6		25
Hong Kong University of Science and Technology	31		18		29
Northwestern University	36	34	23		
Seoul National University		21	32	14	
University of Tokyo		42	35	28	
KU Leuven			37	17	33
Royal Institute of Technology			38	46	35
National Taiwan University	46	39		23	
Huazhong University of Science & Technology		11		13	21
Tianjin University		22		35	37
Texas A&M University, College Station	17	48			47
California Institute of Technology	42		2		
University of Oxford		49	3		
Carnegie Mellon University	26		12		
University of Hong Kong			30		30
Kyoto University			42	48	
University of Washington	42		44		
University of Manchester	35		46		
Monash University			45		71
Pennsylvania State University		30		32	
Dalian University of Technology		32		36	
Tohoku University		45		34	
University of Chicago		41		49	
King Abdulaziz University	5				22
Hong Kong Polytechnic University		29			17
University of California, Santa Barbara	33		31		
Islamic Azad University				38	38
Aalborg University	39				8
Huazhong University of Science and Technology	39				21
Tongji University		43			31
University of Tehran	48				42
Cornell University			20		
Technical University of Munich			20		
Columbia University			26		
RWTH Aachen University			24		
Johns Hopkins University			34		
University College London			36		
University of Wisconsin-Madison			40		
Technical University of Berlin			43		
Rice University			49		

University of Chinese Academy of Sciences		13			
Nanjing University				25	
Pierre and Marie Curie University - Paris 6	25				
King Abdullah University of Science and Technology	29				
Beihang University		37			
Jilin University				37	
University of Minnesota, Twin Cities	37				
Shandong University				44	
University of Granada	45				
Central South University		47			
Ohio State University, Columbus	47				
PRES University of Lyon				47	
Korea University	49				
Karlsruhe Institute of Technology				50	
University of Edinburgh			45		
Sungkyunkwan University (SKKU)			47		

The table shows that there are 18 institutions ranked by all systems in top 50, whereas 15 institutions are common to 4 rankings, and 31 institutions are ranked by at least 2 ranking systems in the top 50. MIT is consistently ranked in the top by all 4 systems, but there is considerable disagreement between cases such as Stanford University and Tsinghua University. ARWU and THE ranked Stanford higher than URAP, NTU, and US News possibly due to the effect of awards in the case of ARWU and the reputation score in the case of THE. Tsinghua University is in the top 5 for all rankings except THE, which ranks Tsinghua University at a considerably lower position at 26th. Chinese institutions are ranked higher in rankings that primarily depend on bibliometric indicators such as NTU and URAP. 36 universities are unique to the top 50 list of a single ranking system, which constitute the cases of most significant deviation from respective ranking systems. There are 6, 3, 11 and 5 such institutions for ARWU, NTU, THE and URAP rankings respectively. Institutions listed in the top 50 of the US News Engineering ranking are all ranked by at least one of the four other rankings. Most dramatic differences in THE engineering ranking relate to Caltech and University of Oxford, which are not ranked highly in the other rankings, which seems to be a consequence of the reputation survey scores.

These five ranking systems are also compared in terms of their mutual rank correlations to explore the degree of similarity between different global engineering rankings. The correlation matrix in Table 7 suggests that NTU and URAP are the most similar (*Spearman* ρ=.76, p<.01), whereas ARWU and NTU also have a positive and significant correlation (*Spearman* ρ=.75, p<.01). The correlation between ARWU and URAP is also high and significant (*Spearman* ρ=.65, p<.01). US News also exhibit high correlations with URAO and NTU. THE is the most dissimilar among the five rankings included in the analysis.

Table 7. Correlations among five global Engineering Rankings

	ARWU	NTU	THE	URAP	US News
ARWU	1.0	0.747**	0.164	0.654**	0.577**
NTU		1.0	0.342	0.775**	0.717**
THE			1.0	0.526*	0.380
URAP				1.0	0.716**
US News					1.0

**p<.01, *p<.05

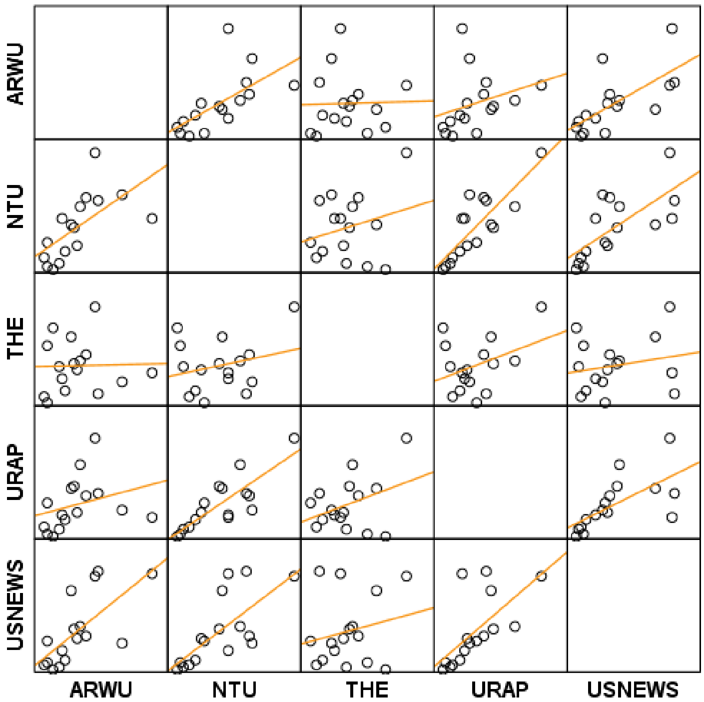

Figure 1. Scatterplots for the five global engineering rankings

Summary of Employed Ranking Indicators

Our review of existing engineering system showed that a multitude of indicators are already employed by different systems. Due to limitations in accessing relevant data at the global scale, international rankings tend to heavily rely on bibliometric indicators as well as reputation surveys. National rankings tend to cover more comprehensive set of indicators due to their advantages in accessing local data sources. The indicators covered so far can be clustered under 5 general themes, namely (i) Academic Excellence/Recognition, (ii) Research Productivity & Impact, (iii) Industry Connections, (iv) Teaching and (v) Finances/infrastructure. A table summarizing existing and possible indicators will be presented in the conclusion section.

Possibilities for Additional Indicators

In this section, possibilities for additional indicators for measuring excellence in engineering are discussed under each general theme identified in the previous section. Each item is discussed based on what is covered in existing rankings, complemented with a discussion of additional elements that could be used to improve existing ranking methodologies.

Academic Excellence & Recognition

Reputation surveys are the primary vehicles used by the QS and THE rankings to account for academic excellence, albeit in a controversial manner due to the subjective nature of survey instruments. QS and THE aim to address concerns about the survey methodology by recruiting a more diverse set of participants including academicians and industry partners. Aggregation of more diverse opinions can potentially provide a better measure of reputation in engineering, provided that the rankers make the survey administration and analysis phases more transparent.

Another dimension captured by the existing ranking systems is the number of distinguished faculty members whose contributions to the engineering discipline are recognized through prestigious awards or memberships in academy of sciences. ARWU is known for its use of the Nobel prize and the Fields medal as an indicator of academic excellence in their world rankings. However, ARWU's general field ranking in engineering has no award criteria, whereas in some of the subject rankings such as Materials Science & Engineering, Environmental Science & Engineering and Computer Science, Von Hippel, Tyler and Turing awards were employed respectively. ARWU chose to use only those awards that have no more than 80% domestic winners (with respect to the location of the awarding institution) and have a reputation score of 0.67 or higher in the IREG's list of international awards report, which reduced their list to the 3 awards mentioned above. However, the choice of the 0.67 threshold is questionable, since IREG's report covers several additional awards relevant for the engineering disciplines, such as the IEEE Medal of Honor, IEEE Edison Medal, and the Franklin Medal, which are highly regarded in the field of Electrical & Electronics Engineering even though the majority of the winners are based in US institutions.

IREG's list of international awards lists 5 awards in cross-disciplinary engineering fields, 5 in chemical engineering, 3 in civil engineering, 7 in electrical and information engineering, 3 in energy science & engineering, 6 in environmental science & engineering, 3 in materials science & engineering and 3 in mechanical engineering. This vast coverage of awards is not reflected in any existing engineering ranking. IREG also provides reputation scores for each award based on a method developed in Zheng & Liu (2015). Considering a weighted sum of the awards with respect to their reputation scores could provide a better indicator for academic excellence in terms of their distinctive service to the corresponding field of engineering.

Besides high profile prizes and memberships to academies of sciences, there are also other important group memberships one can consider for ranking purposes. For instance, IEEE organizes several working groups that include leading engineers in their respective subdiscipline of electrical & electronics engineering to set the standards for manufactured electronics (e.g. the IEEE 802.11 regulates the standards for media access control, influencing all modern telecommunications infrastructure). Having active members in such committees can be considered as indicative of recognition within the specific engineering discipline and evidence of impact on engineering practice.

Finally, another important recognition indicator could be the number of executive editors and editorial board members in top engineering journals. Participation in peer review activities is an important aspect of any scientific discipline, and inclusion in a top journal's editorial team can be considered as a recognition of that researcher's expertise in that domain.

Research Productivity & Impact

The majority of existing engineering rankings focus on research output as the primary indicator of excellence in engineering. This is mainly due to the fact that an institution's overall contribution to engineering can be effectively traced through citation databases such as Scopus and Web of Science. Scopus covers the EI Compandex index, which is one of the major indices specialized for engineering, including not only journals but also proceedings of several engineering related international conferences. Similarly, recent additions such as the Conference Proceedings Citation Index and the increasing coverage of technical edited books in engineering within the Books Citations Index have increased the coverage of engineering related content in Web of Science.

Although engineering is a widely covered discipline in popular citation databases, there are still some special indices maintained by associations and societies such as IEEE (for electrical & electronics engineering) and ACM (for computer science) that provide bibliometric data for their conferences and technical journals, which are not covered in their entirety by bibliometric data providers such as Scopus and Web of Science. ACM Digital Library and IEEE Explore are among such data sources which provide additional information such as the number of times a paper is downloaded by other users, and/or other altmetrics such as the number of times a paper is mentioned in distinct tweets etc. Such measures could serve as complementary indicators to citations, which could be useful for measuring the immediate impact of an institutions' research output. Although such measures do not necessarily carry the same level of significance as citations, as citations take considerable time to accrue, alternative altmetrics may serve as an impact indicator for most recent work of an institution.

Industry Connections

Partnerships with the industry is an important indicator for the impact of a higher education institution specialized in engineering. Existing rankings focus on indicators such as the number of papers co-authored with industry partners and the income from the industry for consulting or collaboration in joint projects to evaluate the strength of an institution's partnerships with the industry. However, indicators based on patents are not considered in any of the international engineering rankings, which can potentially yield important information regarding the economic impact of an engineering program's cumulative intellectual property.

Reuters' The World's Most Innovative Universities is the only ranking that utilizes patent data to list the top 100 most innovative universities in the world[11]. The ranking is based on multiple indicators[12] including the number of basic patents filed by the institution, the ratio of the patents successfully granted, the percentage of patent filings to the US, European and Japanese patent offices simultaneously for international coverage, the number of citations to patents, the ratio of citations per patent, the percentage of patents cited, the percentage of articles co-authored with industry partners and the number of research papers. The ranking is based on the Derwent Innovations Index and the Web of Science database provided by Clarivate Analytics. There are two more rankings which are based on the number of utility patents granted to world universities only by the US Patent Office[13]. In addition to this, the US Patent Office published the number of utility patents granted to the top 250 US universities between the calendar years starting from 1962 to 2012[14].

Although existing patent-based innovation rankings are not focusing on engineering applications per se, they are relevant for engineering rankings since most patents include engineering applications. When the Reuters' ranking is investigated one can observe that it predominantly represents US institutions (50 universities), followed by Japanese (9), French (8), South Korean (8), German (6), English (5) and Swiss (3) universities. The ranking covers only 14 countries, reflecting the bias towards the US, European and Japanese markets, which collectively constitute a huge part of the world's economy. Another important observation is the featuring of entities such as University of California System and University of Wisconsin System, which reflects the different practices followed by different institutions in terms of their patent filing practices. In some countries like Turkey, patent applications are made by individual researchers without any reference to the affiliated university, since the patent law dictates in Turkey that a patent is a person's intellectual property. This situation is likely to change in the near future based on new regulations, but the existing patents do not reflect much university involvement. For that reason, Turkish universities have very few international patents in their

[11] http://www.reuters.com/article/idUSL1N11K16Q20150915
[12] http://www.reuters.com/most-innovative-universities/methodology
[13] http://www.academyofinventors.com/pdf/top-100-universities-2015.pdf
[14] https://www.uspto.gov/web/offices/ac/ido/oeip/taf/univ/org_gr/t250_univ_ag.htm

portfolio. A similar situation may be relevant for other developing countries that may have different regulations for the management of intellectual property rights.

There are several patent search databases such as Derwent Innovations Index offered by Clarivate Analytics or Google Patents, which allow users to search for patents in engineering and related disciplines where the assignee is a higher education institution. Some of these databases do not offer specific naming conventions for higher education institutions, so its challenging to obtain reliable information about the number of patents issued to a given engineering program. For instance, a search for the assignee keyword Massachusetts Inst of Technology revealed 1357 patents in the last 5 years in Derwent, whereas the same time period revealed 6198 results in Google patents. Therefore, without any explicit support from patent databases for indexing institutional names at the departmental level, its difficult to obtain reliable metrics for a given university. Clarivate is currently planning to integrate Derwent into its InCites platform to provide better support for tracing patents and articles through a unified interface, which may help mitigate such issues with patent data. Existing databases primarily focus on data provided by the US, European and Japanese patent offices, which may be a disadvantage for those institutions that are granted patents through their national patent offices. However, one can make the argument that seeking patent coverage in major markets like US, Europe and Japan may indicate that the invention has commercial value, given the labor and costs involved with filing an international patent.

Another indicator showing the value of a patent could be the number of citations it received from other patents or scientific journals. Both Derwent and Google patents provide such citation measures, some of which are already employed by Reuters' innovation index, including the distinction between patent applications and the patents granted. What is not covered so far seems to include the patents that are co-authored by industry partners, and patents licensed by companies, which can be considered as important industrial impact indicators as well. There are also powerful analytics tools such as Innography, InnovationQ, LexisNexis which can estimate the approximate intellectual property valuation of universities through their patent analysis algorithms. Such indicators could be important in following the potential impact of that institution in the near future based on its intellectual property portfolio. However, with the exception of Google's patents database, which indexes content from 17 patent offices[15], none of these tools provide open and free access to their data and analytics resources.

Teaching Excellence

With the exception of U.S. News national engineering ranking, all existing ranking systems rely on indicators such as staff to student ratio, the ratio of doctoral to bachelor students, the percent of international students to include teaching related measures in engineering rankings. U.S. News is the only national ranking that uses Accreditation Board for Engineering and Technology (ABET)

[15] https://support.google.com/faqs/answer/7049585?hl=en&ref_topic=6390989

accreditation as an indicator of excellence in engineering teaching, which features only ABET accredited engineering schools in the U.S. Some national rankings also administer student satisfaction surveys, which include their assessments regarding the quality of coursework and their prospects for finding a job upon graduation, but they are limited to the country of interest.

Engineering education requires expensive lab infrastructure, carefully executed curricular activities, close connections with the industry and a sound curriculum balancing theory and practice in applied sciences. Accreditation organizations such as Accreditation Board for Engineering and Technology (ABET) and the European Network for Accreditation of Engineering Education (ENAEE) evaluate programs that offer engineering degrees along several criteria including their curricular organization, lab infrastructure and learning outcomes. Therefore, institutions with accredited engineering degree programs conform to teaching quality standards set by the accreditation bodies.

Accreditation.org provides an index of existing accreditation bodies from 84 countries specializing on engineering disciplines. Due to the common goals pursued by most accreditors of engineering programs, several Mutual Recognition Agreements have been signed between countries such as the Washington Accord of 1989 and the Bologna Declaration of 1999[16] that identify the common principles and quality assessment practices in engineering disciplines. Since ABET and the ENAEE are among the largest accrediting bodies of engineering, our review will focus on the principles and guidelines published by these organizations.

Accreditation Board for Engineering and Technology (ABET)

ABET was established in 1932 as the Engineers' Council for Professional Development (ECPD), an engineering professional body dedicated to the education, accreditation, regulation and professional development of engineering professionals and students in the United States[17] (Prados et al., 2005). Today, ABET involves 35 member societies, including the American Institute of Aeronautics and Astronautics, American Institute of Chemical Engineers, American Society of Civil Engineers, IEEE, and American Society for Engineering Education (Pool, 2016). ABET accredits programs in engineering, engineering technology, applied science, and computing at colleges and universities around the world. Although ABET is based in the US, currently ABET accredits 3,709 engineering programs at 752 colleges and universities located in 30 countries. ABET's accreditation of a program suggests that the graduates of that program are well-prepared for a career in the professional practice of engineering due to the quality standards met by their degree program.

The ABET accreditation process typically takes 18-21 months, and is carried out based on self-evaluations by the institution and the reports of external program evaluators from other institutions

[16] http://accreditation.org/accords/mutual-recognition-agreements
[17] http://www.abet.org/about-abet/history/

(ABET, 2015). Pool (2016, p.3) summarizes the 8 general criteria employed by ABET for the evaluation of an engineering program:

- Criterion 1 concerns students, specifically monitoring to foster their success, assessment of their progress and performance, admission procedures, assignment of academic credit, and other related issues.
- Criterion 2 concerns the program's educational objectives, which must be consistent with the ABET criteria. Program educational objectives define what the graduate is expected to be able to do 3–5 years after graduation.
- Criterion 3 concerns student outcomes, such as the abilities to apply knowledge of mathematics, science, and engineering; to design a system within economic, social, ethical, global, and other constraints; to function on multidisciplinary teams; to recognize of life-long learning and contemporary issues; and to communicate effectively.
- Criterion 4 concerns institutional quality management systems and how they assess whether and to what degree programs succeed in accomplishing stated learning outcomes.
- Criterion 5 specifies curricula: An engineering degree program must include, for example, 1 year of mathematics and basic sciences; 1½ years of various engineering topics, including design and practical application; a culminating design project; and a general education component that is consistent with the program's educational objectives.
- Criterion 6 concerns faculty numbers, qualifications, and competence; interactions with students as well as industrial and professional practitioners; and professional development.
- Criterion 7 concerns facilities, including laboratories, equipment, resources, and supporting infrastructure.
- Criterion 8 concerns institutional support such as funding and staffing to ensure the quality and continuity of the program.

Detailed descriptions of each criterion can be accessed in ABET's guidelines (2015). Slightly more research oriented criteria are defined for accrediting master level programs, where the emphasis is put on whether students mastered an advanced field within their profession. Currently there is no accreditation for doctoral degree programs.

ABET also uses guidelines specific to each engineering discipline, which are overseen by the relevant society in that discipline. For instance, the following guidelines are provided for the Aerospace and similarly named engineering programs which is led by the American Institute of Aeronautics and Astronautics (ABET, 2015, p. 8):

1. Curriculum: Aeronautical engineering programs must prepare graduates to have a knowledge of aerodynamics, aerospace materials, structures, propulsion, flight mechanics, and stability and control. Astronautical engineering programs must prepare graduates to have a knowledge of orbital mechanics, space environment, attitude determination and control, telecommunications, space structures, and rocket propulsion. Aerospace engineering programs or other engineering programs combining aeronautical engineering and astronautical engineering, must prepare graduates to have knowledge covering one of the areas -- aeronautical engineering or astronautical engineering as described above -- and, in addition, knowledge of some topics from the area not emphasized. Programs must also prepare graduates to have design competence that includes integration of aeronautical or astronautical topics.

2. Faculty: Program faculty must have responsibility and sufficient authority to define, revise, implement, and achieve program objectives. The program must demonstrate that faculty teaching upper-division courses have an understanding of current professional practice in the aerospace industry

European Network for Accreditation of Engineering Education (ENAEE)

ENAEE was founded in 2006 as a product of the EUR-ACE project which is rooted in the Bologna process that aim to establish a European higher education area by strengthening European higher education and supporting mobility of students and faculty. In particular, ENAEE aims to "…enhance and promote the quality of the education of engineering graduates in order to facilitate their professional mobility and to enhance their individual and collective ability to fulfil the needs of economies and of society" (ENAEE, 2015, p.1). However, ENAEE does not accredit engineering degree programs, it provides a set of standards that are used for accreditation purposes by several agencies based in primarily EU countries. When an accreditation and quality assurance agency applies for authorization to award EUR-ACE® label to engineering degree programs, ENAEE evaluates the policies and procedures implemented by such agencies for eligibility. ENAEE sets a general framework for the accreditation of engineering education programmes in Europe and abroad, which is implemented through agencies distributed among several countries. As of January 2017, ENAEE has currently 21 full members and 4 associate members, covering mainly accreditation agencies from EU member countries plus Russia, Turkey and Kazakhstan.

The guidelines provided by ENAEE are not fundamentally different from those of ABET. A main difference is that ENAEE facilitates a decentralized body of agencies who are implementing the accreditation process, and thus ENAEE also provides guidelines and principles for the necessary qualifications of accrediting bodies themselves, which could be informative for ranking researchers to reflect upon.

Summary

The information provided in the ABET or ENAEE guidelines suggest that accreditation can be a useful indicator for the assessment of teaching excellence in engineering. The accreditation process focuses on difficult to assess features such as characterization of expected program outcomes in engineering, the realization of those learning outcomes by the students, the development of communication, design and problem solving skills in engineering, the effectiveness of curriculum for teaching science and engineering concepts, etc. However, despite the attempts for establishing international standards and mutual agreements, since there is no universal accreditation organization institutions may have been accredited by different international and national accreditation bodies. A ranking indicator that may take into account the mutual agreements at the international level (e.g. the Washington accord) may be useful in terms of quantifying teaching excellence as recognized by different accreditation schemes.

Finances, Infrastructure

Engineering education and research requires significant investments on labs, equipment and infrastructure. The diversity of a university's engineering degree programs, the variety of functioning labs, the annual budgets and income related to engineering can serve as important indicators of physical and financial infrastructure. Infrastructure needed for effective engineering education is also covered as a key indicator in accreditation schemes such as ABET.

Many engineering schools have strong connections with science centers or technopolis infrastructures to stimulate the transfer of academic knowledge in the service of practical applications. The number of faculty members serving as advisors/collaborators to such engineering firms, and the number of companies spun off from engineering departments can be considered as other potentially useful indicators for ranking engineering institutions. The revenues and the number of jobs generated by such companies can be also used as a measure of their economic and societal impact.

Engineering programs are typically housed in dedicated buildings together with spaces for classrooms as well as labs. Some universities may also offer centralized lab resources that can be put in the service of engineering students and faculty. Such infrastructural elements can be quantified based on the raw measures such as squared meters of lab/classroom space as well as inventories of available lab equipment for research and education.

However, accessing this kind of data through independent, third-party data sources is not feasible. Ranking institutions tend to contact the institutions to request information about their budgets allocated for specific programs, the number of faculty members, students, etc. Such data collection schemes always run the risk of obtaining inaccurate data, and it is usually difficult to verify the data collected from each university.

Conclusion

This report aimed to summarize the viewpoints of key stakeholders in engineering disciplines and to identify a set of relevant indicators catering to the key attributes voiced by the stakeholders. The report also reviewed existing international and national ranking systems focusing on engineering disciplines. Existing rankings already cover many useful indicators, but they differ in terms of the selected indicators for ranking purposes (e.g. only U.S. News considers ABET accreditation as a filter, whereas only ARWU uses awards, and a few rankings employ surveys to evaluate reputation). As our ranking comparison analysis showed, such differences may lead to some important differences among ranking results. Given the diversity of the approaches and the wealth of indicators based on relevant data sources, the development of a more comprehensive engineering ranking that can evaluate various dimensions of excellence in education, research and societal impact seems to be highly plausible.

The report also presented some additional indicators based on patents and accreditation schemes, which may be useful for the initiative for constructing a more comprehensive ranking of engineering institutions. In particular, accreditation schemes provide useful characterizations of excellence in engineering education, whereas patents provide insights regarding the contributions of engineering programs to professional practice and the global economy. However, there are also important limitations in the use of these potential indicators. For instance, accreditation processes usually provide a binary outcome (i.e. accredited or not), which suggests that the institution meets an acceptable level of the expectations stated in the accreditation guidelines. Therefore, its difficult to assess if the accredited institution really excels in one dimension, whereas it barely meets the minimum at another dimension. If accreditation reports can be disclosed publicly, then this process may have a significant contribution to the ranking efforts in engineering. In the case of patents, there are differences among countries in terms of their intellectual property laws, and the ways patents are granted nationally may be subjected to different standards. Like papers, not all patents are equally valuable, so one needs additional indicators such as whether the patent was granted in multiple countries, whether it was cited and/or licensed to better judge the quality of patents issued to a university. Since patents can be granted to individuals, it may be difficult to associate many patents that are of academic origin.

Overall, our review of existing engineering system showed that a multitude of indicators are employed by different systems, which are summarized in Table 8 under 5 general themes, namely (i) Academic Excellence/Recognition, (ii) Research Productivity & Impact, (iii) Industry Connections, (iv) Teaching and (v) Finances/infrastructure. A synthesis of all indicators reviewed as well as some potentially useful new indicators are summarized in Table 8.

Table 8. A summary of indicators proposed and currently used for an international engineering ranking

General Theme	Indicator	Used by	Data Source
Academic Excellence, Recognition, Prestige	Academic reputation	QS, THE, US News, Maclean's, Perspektywy	Survey, peer & recruiter assessment
	Highly cited researchers	ARWU, NTU	Highly Cited Researchers List
	Number of faculty who are special members	US News, UK Complete Univ Guide	Academy of Science lists, Excellence List
	Awards (Alumni & Staff)	ARWU	IREG international awards list
	Editors of (high impact) journals in the related engineering subject area		Journal Homepages
	Editorial board members of (high impact) journals in the related engineering subject area		Journal Homepages
	Memberships in international standardization committees (e.g. IEEE work groups)		WWW
Research Productivity & Impact	Publications in Engineering	NTU, URAP, ARWU, Maclean's (fractional), Perspektywy, U-Multirank, US News	Scopus, Web of Science
	Citations	URAP, THE, Maclean's (fractional), U-Multirank	Scopus, Web of Science
	Citations per paper	QS, Perspektywy	Scopus, Web of Science
	Average annual citations	NTU	Web of Science
	H-index	NTU, Perspektywy	Scopus, Web of Science
	H-index citations	QS	Scopus, Web of Science
	Field normalized impact	URAP, Maclean's, ARWU	InCites, SciVal
	Papers in Top 20%	ARWU, US News	Scopus, Web of Science
	Papers in Top 1%	ARWU, US News	Scopus, Web of Science
	International Co-authorship	ARWU, URAP, U-Multirank, US News	Scopus, Web of Science
	Research quality rating	Perspektywy	Higher Education Council
	Number of article views and downloads		SciVal, ACM, IEEE Explore
	Field normalized article views and downloads		SciVal
	Number of papers in high impact journals (e.g. could be based on field normalized impact factor quartiles)	URAP, ARWU	InCites
	Papers co-authored with industry	ARWU, U-Multirank	Scopus/SciVal, InCites
	Industry Income	THE	Survey

Industry Connections	Percent of graduates employed by industry	UK Complete Univ Guide	Higher Education Statistics Agency
	Employer reputation	QS, Perspektywy	Survey
	Number of instructors from the industry	L'Etudiant	Survey
	Number and percentage of students who completed an internship at a company	L'Etudiant	Survey
	Minimum internship duration	L'Etudiant	Survey
	Number of start up companies spun off from the university	L'Etudiant	Survey
	Number of graduates who started a business	L'Etudiant	Survey
	Number of companies and SMEs that participated in the business forums hosted by the university	L'Etudiant	Survey
	Number of graduates obtained through the school's alumni network	L'Etudiant	Survey
	Number of former members of the engineering program enrolled in the LinkedIN page of the school	L'Etudiant	LinkedIN
	Number of faculty members serving as consultants to engineering firms		Survey
	Number of EUR ING title holders in the alumni group		FEANI
	Number of basic patents filed	Reuters WMIU, Perspektywy	Derwent Innovation Index, Google Patents
	Ratio of patents granted	Reuters WMIU	Derwent Innovation Index, Google Patents
	Percentage of patents simultaneously submitted to US,EU and Japanese patent offices for international coverage	Reuters WMIU	Derwent Innovation Index, Google Patents
	Number of citations to patents	Reuters WMIU	Derwent Innovation Index, Google Patents
	Percentage of patents cited	Reuters WMIU	Derwent Innovation Index, Google Patents
	Ratio of citations per patent	Reuters WMIU	Derwent Innovation Index, Google Patents
	Number of citations from patents	U-Multirank	Derwent Innovation Index, Google Patents
	Number of patents co-authored with industry partners		Derwent Innovation Index, Google Patents
	Number of patents licensed by industry		Derwent Innovation Index, Google Scholar
	Approximate intellectual property valuation based on patent portfolio		Innography, InnovationQ, LexisNexis
	Approximate intellectual property valuation based on patent portfolio (GDP adjusted)		Innography, InnovationQ, LexisNexis

Teaching Excellence	Student satisfaction	UK Complete Univ. Guide	National Student Survey
	Program reputation	Maclean's, THE	Survey
	Staff to student ratio	THE, U-Multirank	Survey
	Academic staff with advanced degrees	Perspektywy, U-Multirank	Survey
	Number of PhD students funded by engineering programs	L'Etudiant	Survey
	Number of PhDs awarded	Perspektywy	Higher Education Statistics
	Number of academic staff with highest qualification	Perspektywy, L'Etudiant	Higher Education Statistics
	Doctorate to bachelors ratio	THE	Survey
	Student selectivity, entry standards	US News, UK Comp. Univ. G.	Higher Education Statistics
	Doctorates awarded to academic staff	THE	Survey
	International to domestic student ratio	THE	Survey
	International to domestic staff ratio	THE	Survey
	International PhDs awarded	U-Multirank	Survey
	Accredited programs	US News, Perspektywy	ABET, ENAEE database, National Accreditation Agencies
	Duration of accreditation	L'Etudiant	National Accreditation Agencies
	Acceptance rate	US News	Survey
	Average grade point average of incoming students	L'Etudiant	Survey, Higher Education Statistics
	The presence of a campus abroad	L'Etudiant	Survey
	The required level of English proficiency	L'Etudiant	Survey
	Minimum duration spent abroad for internship	L'Etudiant	Survey
	Number of students and staff participated in academic exchange program	L'Etudiant	Survey
	Number of students in dual degree program with an international institution	L'Etudiant	Survey
	International visibility of the program in global rankings	L'Etudiant	Survey
	Number of dual degree holders	L'Etudiant	Survey
Finances, infrastructure	Research income	THE	Survey
	Institutional income	THE	Survey
	Total research expenditure	US News	American Society for Engineering Education
	Total research expenditure per faculty	US News	American Society for Engineering Education
	Total engineering related expenditures	ARWU	American Society for Engineering Education
	Percent of lab facilities within the building space		Survey
	Engineering related library resources		Survey

Table 8 suggests that a large number of indicators have been employed in existing engineering rankings. Indicators that are not matched with an existing ranking correspond to indicators identified through our analysis of stakeholder comments. Bibliometric indicators are the most frequently used indicators in almost all reviewed rankings. Reputation surveys and peer assessments also take a significant weight in many existing rankings. Ranking systems that employ such reputation indicators tend to assign high ratings to some well-known engineering schools in the US and UK, which also relate to academic distinction indicators such as the number of faculty with internationally recognized awards in engineering. Rankings that mainly rely of bibliometric data tend to favor Chinese institutions, who are experiencing a burst in the number of publications as well as citations. In such rankings some of the better known western universities can be listed in surprisingly low ranks. Another important point is that some of the key data about teaching and finances are collected via institutional surveys, so these indicators are based on self-reported data. Since its challenging to independently verify those figures such as research expenditures or even the number of full time faculty members, such surveys run the risk of producing misleading indicators. Moreover, economic parameters such as expenditures need to be adjusted with respect to a baseline measure such as the gross national product, so as to make a fair comparison among institutions from different countries, especially from developing nations. Advanced analytics over patent databases as well as information about alumni network through professional networking sites may require additional funding. Moreover access to bibliometric data through services such as Scopus, Web of Science, SciVal, InCites also require subscription.

In conclusion, one can argue that there are several data resources that can be employed to produce a more comprehensive ranking of engineering programs that will cater to the information needs of various stakeholders. The relative merits of the proposed indicators in Table 8 should be first tested on a representative sample of HEIs. Given the efforts led by FEANI and EENEA in Europe, a regional engineering ranking for the EU zone could be a good starting point to explore these indicators and challenges involved with data collection and processing.

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Anexes

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Annex

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Annex

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Waldemar Siwinski, Vice President, IREG Observatory

IREG Ranking Seminar in Moscow, 30 November 2017

New Approaches to Design and Collection of Data for Subject and Discipline Rankings

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IREG Observatory on Academic Ranking and Excellence

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)