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Scientific activity evaluation in Poland: the IT ecosystem and the optimal selection of achievements

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Abstract

This article briefly introduces the scientific evaluation process in Poland and its implications in software development. The process, which is organised by the National Information Processing Institute on behalf of the Polish Ministry of Science and Higher Education is the best developed in Europe in terms of the range of data it processes for parametric evaluation supported by IT systems. The process is highly complex; the most significant difficulty lies in the selection and application of quantitative criterion. This article emphasises the importance of sufficient IT systems to support the process, and pays special attention to the algorithmic problem of selecting the scientific achievements to be assessed optimally.

1. Introduction

This article focuses on the technological aspect of the assessment of scientific achievements. We define the evaluation process highly specifically as a nationwide activity that periodically assesses the quality of the scientific activity of scientific entities. These types of activity differ widely in their nature

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and form. In evaluation, three methods are frequently used to measure the scientific effectiveness of a unit: peer-review-based models, publication-count-based models, and citation-based models. Mixed methods are commonplace; usually, however, they chiefly comprise quantitative methods. Mixed methods involve quantitative assessment of some scientific achievements (e.g., publications) and evaluation of others by experts (e.g., the impact of research results on the development of a field).

2. Systems of evaluation of scientific achievements

Due to the dynamic development of science in the second half of the twentieth century, systems in which scientific institutions became dependent on the results of science were introduced. These evolved into national systems for assessing the scientific excellence of individual institutions; that is, systems for evaluating scientific activity. This was necessary to determine the resources states allocated to research.

The earliest example of an evaluation system is the British Research Assessment Exercise of 1986, which relied solely on expert judgment. In 2014, a modified Research Excellence Framework was adopted, which—in a slightly altered format—continues to function at present and has become a reference point for the construction of evaluation systems in other countries.

Since the beginning of the 1980s, the Dutch Standard Evaluation Protocol has been used to evaluate the nation’s scientific institutions. Other systems exist, such as the French evaluation system, *Sexenios de investigación* in Spain, Research Unit Evaluation in Portugal, Excellence in Research for Australia, Performance-based Research Funding in New Zealand, as well as systems in Poland and in other countries.

The operation of evaluation systems has become increasingly complex. The effectiveness of scientific activity is evaluated on the basis of various aspects, including publications, projects, and participation at conferences. A number of indicators have been designed for these aspects’ assessment, including impact factors and the Hirsch index. They are designed to present the quality of science quantitatively and objectively; they also serve, however, to complicate the evaluation system and occasionally lead to research activity focusing on the attainment of high scores at the expense of more valuable pursuits. For that reason, it is necessary that evaluation systems’ effects be analysed and modified continually (Michajłowicz M. 2021).

3. The Assessment System in Poland

Evaluation commenced in Poland in the early 1990s. Initially, the procedure was highly complex and involved a dizzying array of indicators. This early system was based on annual surveys submitted by scientific units. Later, units were required to provide the required data only in the runup to the evaluations, for the entire evaluation period. Since 2017, evaluation has been performed using only data that is contained in the POL-on system.

‘Third generation’ evaluations commenced in 2010. Evaluations based on the new rules were performed for the first time in 2013. Most of the solutions adopted at that time were used again in the most recent evaluation of 2017. Any scientific achievement, such as publication of a monograph or a scientific article, constituted an evaluation event. For the purposes of the 2017 evaluation (2013–2016), over one million evaluation events were reported by 994 research units that employed approximately 86,500 researchers (Michajłowicz M. 2021).

4. Scientific activity evaluation system for 2017-2021

The system for evaluation of scientific achievements for 2017–2021 is the result of a reform of science implemented by the Polish Minister of Science and Higher Education in 2018 as part of Act 2.0. The reform has influenced the shaping of state science policy. Its key elements are a change in the form of evaluation of scientific activity and an increased role for the categories assigned in this way into a number of processes. These include the linking of evaluation results with an algorithm that allocates funds under subsidies, and authorisation to award academic degrees in disciplines that have attained the relevant scientific categories (A+, A or B) by scientific units as a result of the evaluation.

The conclusions of previous evaluations indicated that too many achievements had been assessed and that the evaluation system was too complex (Kulczycki E., 2017). All of this data had to be reported by entities then verified against the limits.

The key changes from previous evaluations are: new classification of scientific disciplines, maximum four publications per person, fractional counting of publications, five instead of four categories, a transition from organisational to qualification-based classification, a new list of journals, the introduction of a list of publishers and conference proceedings, and a reduction in the number and types of evaluated achievements.

5. The Integrated System of Information on Science and Higher Education in Poland

The Integrated Information System on Science and Higher Education (POL-on)—which has been operational since 2011—is an extensive collection of repositories on science and higher education at the disposal of the Polish Ministry of Science and Higher Education and other institutions listed in the Act (Ustawa... 2018). The system was developed by experts at the National Information Processing Institute (OPI PIB). Detailed data and the evolution of the system's scope are presented by Michajłowicz (2018).

POL-on is a set of autonomous microservices and applications dedicated to collecting a wide range of data on scientific achievements, didactics, finances, and other factors that contribute to the evaluation process. Architecture prepared for the needs of the RAD-on portal was used to integrate the data, as described in Protasiewicz (2019) and Protasiewicz (2021). Reports, Analyses, Data (RAD-on) served as the architectural foundation in data integration from many sources with a diversified structure. The same system was used to feed the Scientific Evaluation System (SEDN) system with data to source systems, such as POL-on and the Polish Scientific Bibliography (PBN).

SEDN is a separate application dedicated solely to supporting scientific evaluation.

The detailed scope of services and data necessary for the implementation of the process is as follows:

1. **POL-on** (https://polon2.opi.org.pl/) covers domain objects, such as: a) institutions that participate in the evaluation; b) people, including employees and participants at doctoral schools; c) patents for inventions, protection rights for utility models, and the exclusive rights of plant variety breeders submitted for evaluation; d) scientific projects involving R&D works conducted during the evaluation period (2017–2021); e) artistic achievements that were created with employment or training in the subject; f) financial data, including revenues from commercialisation of R&D works and knowledge related to their results; and g) impact descriptions of scientific activity on the functioning of society and the economy that describe the relationship between the results of scientific R&D works or scientific activity in artistic creation and the economy, the functioning of public administration, public health, culture and art, environmental protection, state security and defence, or other factors that influence the

development of civil society. A dedicated application, *Studnia* (https://studnia.opi.org.pl) was used to collect evidence of the impacts of scientific activity on the functioning of society and the economy presented in the impact descriptions (in the POL-on system).

2. **PBN** (https://pbn.nauka.gov.pl/) covers domain objects, such as scientific publications, under which various types of publication are registered and evaluated: authorship of articles, authorship of conference materials, authorship of monographs, authorship of chapters, and editorial information.
3. **SEDN** (https://sedn.opi.org.pl/) is part of the POL-on system. It provides the functionalities required for entity evaluations to be conducted. SEDN collects information necessary for evaluation from data collection systems and presents it in terms of evaluation of the quality of scientific activity for each entity. The system incorporates an optimisation algorithm (see section 8), approvements of final lists of scientific and artistic achievements, expert assessment of artistic achievements, and final reports of evaluation results.

A schematic illustration of the systems and dependencies is presented in Figure 1:

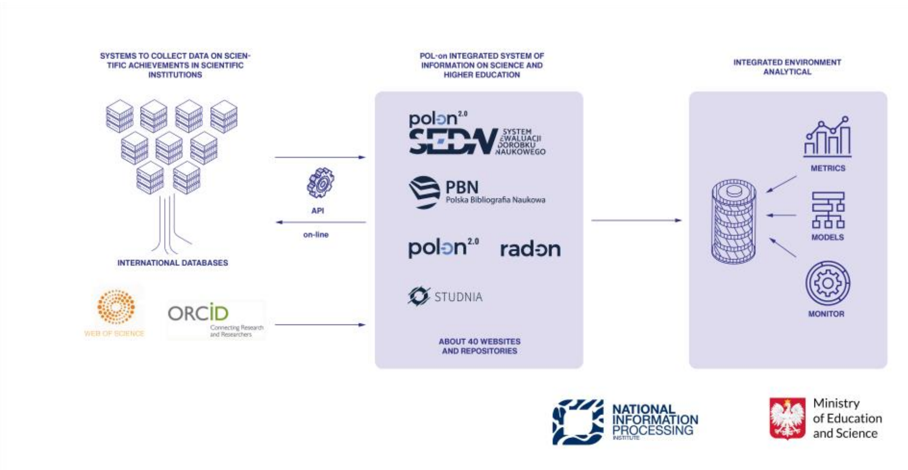

Figure 1. Diagram of data flow between systems

The scale of the project is best illustrated by the data on the achievements of 2017–2021, collected and submitted for the purposes of evaluation:

Indicator	Value on 31.01.2022
Number of entities evaluated	291
Number of people evaluated in SEDN	117,854
Number of publications	707,862
Number of artistic achievements	53,903
Number of protection rights	12, 138
Number of research projects.	27,556
Number of entries with revenues from commercialisation	16,002
Number of entries with revenues from research services provided on request	155,867
Number of impact descriptions	2,659

Table 1. Evaluation statistics based on a dedicated application for presenting key process performance indicators (KPIs): https://statystyki-ewaluacja.opi.org.pl/

6. System interoperability: integration with other external sources

POL-on supports interoperability with the following databases and websites:

- **ORCID (**https://orcid.org/**).** Open Researcher and Contributor ID, is a global non-profit organisation. It provides a persistent digital identifier (an ORCID iD) that researchers own and control, and that distinguishes them from other researchers. It enables transparent and trustworthy connections between researchers, their contributions, and their affiliations by providing a unique, persistent identifier for individuals to use as they engage in research, scholarship, and innovation activities. During the development of the PBN module, researchers were able to import and export publication data to and from ORCID easily. In PBN, almost 100,000 researcher profiles contain ORCID identifiers. PBN incorporates an ORCID API to expand its set of features and data within the local system; in other words, it enables users to import and export publication records between systems
- **WoS (**https://www.webofscience.com**).** Web of Science is a website that enables subscription-based access to multiple databases that provide comprehensive citation data for a wide variety of academic disciplines. It is currently owned by Clarivate (formerly Clarivate Analytics). For the purposes of the 2017–2021 Polish evaluation, Clarivate periodically provided data in XML format on publications of which at least one author had Polish affiliation. The publication, published between 2017 and 2021, comes from its indices. Such XML dumps were extracted, transformed, and loaded on to the OPI PIB data warehouse. OPI PIB received an increase in publication data, which after applying filters amounted to a total of 230,000 publications from WoS. They were used in the process of verifying publications collected on individual accounts of Polish scientific institutions at the PBN. The final result of the publication verification was calculated on the basis of many assumptions. Ultimately, due to a large number of negative results, the author affiliation verification was excluded from the calculation of the final, aggregate verification result. Almost 40% of articles were assigned a positive verification status, and a little more than 10% a negative one.
- **EPO (**https://www.epo.org**).** Open Patent Service is a web service designed to perform automated queries, such as automated data retrieval (by robots) and access via third-party portals (e.g., software packages). They offer similar sets of data as the European Publication Server, the European Patent Register and Espacenet. Open Patent Services (OPS) is a web service that enables access to the EPO's data via a standardised XML interface using RESTful architecture. The connection with OPS was used to verify the data on patents recorded in POL-on.

7. Optimising algorithm

Evaluation involves optimising scientific achievements (articles and shares in articles) for each institution in a discipline. A share is an object that describes how much of a scientific article is assigned to a specific person. For example, if an article is worth 100 points and has only one author, the share count for that author has a value of u = 1 and is worth p = 100. If an article worth 100 points has two authors, both of them have a share count of u = 0.5 and each is worth p = 50. The objective of this process is to select shares that maximise the scores (points sum) of whole institution–discipline entities, with respect to limits for institution, for person, or for share.

Institution, based on the number of people employed, entails the following limits:

- limit_3n_u as integer – limit for shares (u) sum
- limit_opn as floating point – limit for shares (u) sum that are taken by people outside N
- limit_mono_p as floating point – limit for shares (u) sum for monographs and editorials whose share value (p) exceeds 100 points
- limit_m1921 as floating point – limit for shares (u) sum, that comes from articles, monographs, editions, and chapters written in 2019–2021.

Person, based on their type of employment at an institution and statement of discipline, entails the following limits:

- limit_all_u as floating point – limit for sum of shares (u) related to a specific person chosen by optimisation process,
- limit_mono_o as floating point – limit for sum of shares (u) related to a specific person for monographs and editorials of which share value (p) exceeds 100 points

Share has only one limit, which is related to chapters. Monographs can be reported as single entities or be divided into chapters that can be reported separately. The points sum for chapters in a monograph cannot exceed the number of points assigned for that monograph (Figure 2).

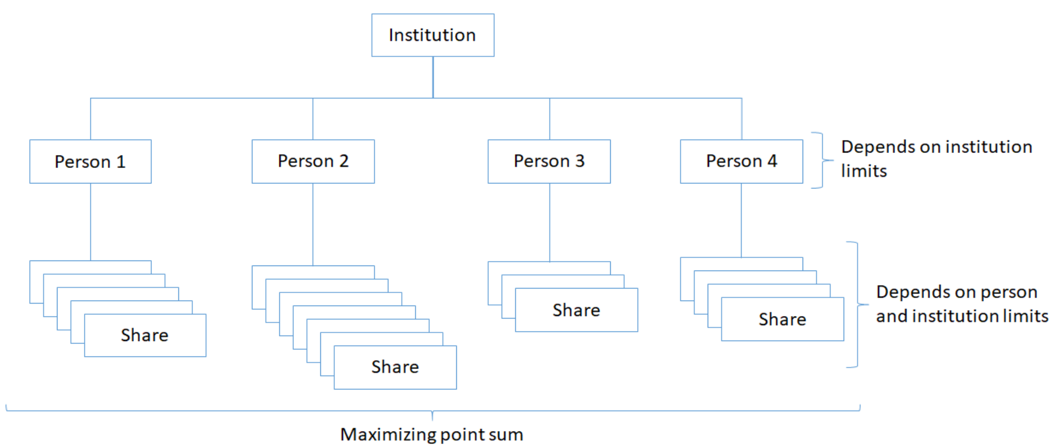

Figure 2. Conceptual data view in optimization process.

The process belongs to the non-polynomial category problem, which means that to ensure that scores are maximised, every combination of shares should be considered. That causes the problem to be an exponential one. For ten shares to be optimised, 2^10 = 1024 permutations of those shares must be checked.

Mathematically, the process involves:

1. X – vector of integers [0, 1], which represents whether a share is taken or not (unknown)

2. U – vector of share values (given)
3. P – vector of share points (given)

The optimisation function:

$$argmax(X \bullet P)$$

Optimisation limits (by institution, all people, and all chapters):

$$\begin{cases} X \bullet U \leq limit\_3n \\ X \bullet U \leq limit\_m1921 \\ \dots \end{cases} \quad \begin{cases} X \bullet U \leq limit\_person\_1 \\ X \bullet U \leq limit\_person\_2 \\ \dots \end{cases} \quad \begin{cases} X \bullet U \leq limit\_chapter\_1 \\ X \bullet U \leq limit\_chapter\_2 \\ \dots \end{cases}$$

The optimisation algorithm is based on genetic algorithms. The problem is not described traditionally (by a formula for obtaining the optimal result), but by describing the limitations of the result and the definition of the objective function; as in nature, the algorithm measures the adaptation of an individual to their environment—in this case to limitations.

The optimised object in this case is a vector of discrete integers (0 or 1) that describes whether a given share is included in the result or not. The optimisation algorithm using the mutation operation (exchanging a random number in the vector), crossing (taking a part of the vector from one solution and a missing part from the other), using the evaluation function, and repeating this process many times during subsequent generations (creating random crossovers and new vectors and selecting only those with the highest score) leads to the maximisation of scores.

Initial vectors for the genetic algorithm are generated based on constraint programming solvers (ORTools: https://developers.google.com/optimization) that are applied to solve this particular problem:

1. BOP_INTEGER_PROGRAMMING
2. SCIP_MIXED_INTEGER_PROGRAMMING
3. SAT_INTEGER_PROGRAMMING
4. GLOP_LINEAR_PROGRAMMING
5. CLP_LINEAR_PROGRAMMING
6. CBC_MIXED_INTEGER_PROGRAMMING
7. KNAPSACK_MULTIDIMENSION_CBC_MIP_SOLVER
8. SORT (sorts shares by score and takes the most valuable first)

The process is executed simultaneously in iterations, then gathered to compute final scores:

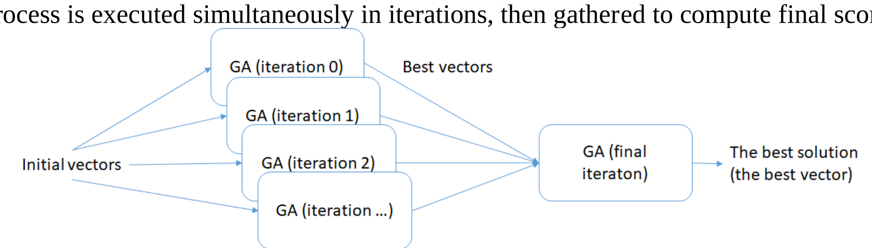

Figure 3. Optimization pipeline..

This solution entails several assumptions and restrictions:

1. A function that exists in multidimensional space (as many spaces as shares), which has extrema
2. The functions that are maximised are stable (one minor change in X does not change the output score considerably)
3. Using the genetic algorithm does not guarantee the best possible score. As time is spent on solving the problem, the system can only produce the most probable result

The process has been executed on 1,097 institution–discipline entities on a 600-core docker cluster and generated 150 sequential results per institution–discipline (total: 164,550) to ensure that the maximum possible score has been achieved. This was repeated every night on the demo version of SEDN for more than three months before the final evaluation. The demo version of the SEDN module was made available to scientific entities. Their representatives were able to control the data entered into POL-on and PBN in SEDN, clarify doubts and inconsistencies, verify the data, and modify the set of publications submitted for evaluation. As a result of their access to SEDN, scientific entities know the scoring of their scientific achievements—although they cannot compare them with other entities.

8. Conclusion

Polish evaluation is one of the most complex processes in terms of parametric evaluation, since it is based on a very large and complex range of data on scientific achievements. The experience of previous evaluations has made decision-makers aware of the key role that appropriate software plays in this process. One example of its role can be seen in the preparation of appropriate algorithms to optimise the selection of achievements to be evaluated. As a result of the three-year project, an extensive system comprising several dozen microservice applications, an integrated analytical environment, and a number of analytical tools that successfully integrate with international scientific databases was created. This system will be the foundation of future evaluations in Poland.

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