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**CHEN JIE**

**UDC 004.58+378**

**PHD THESIS**

**MODELS AND METHODS FOR ASSESSING THE COMPETITIVENESS  
OF UNIVERSITIES' EDUCATIONAL ACTIVITIES IN THE CONTEXT  
OF DIGITAL TRANSFORMATION**

122 Computer Science  
12 Information Technology

Applying for the Doctor of Philosophy degree

The PhD Thesis contains the results of own research. The use of ideas, results and texts of other authors are linked to the corresponding source

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## SUMMARY

### **Chen Jie. Models and Methods for Assessing the Competitiveness of Universities' Educational Activities in the Context of Digital Transformation.**

– *Qualifying scientific work as a manuscript.*

Thesis for the Doctor of Philosophy Degree in Specialty 122 «Computer Sciences». – Taras Shevchenko National University of Kyiv, Kyiv, 2023.

**Abstract content.** The dissertation is devoted to constructing models and methods for evaluating the competitiveness of educational activities of universities in the conditions of digital transformation. The built models and methods can be applied to solve the actual scientific and practical task of increasing the competitiveness of universities, taking into account the peculiarities of educational activity.

The practical activity of universities ensures the state's development and the emergence of innovations and ideas. Now, in the conditions of digital transformation, many factors influence this activity. A large number of parameters are difficult to measure, and they have different types of data; in addition, it is difficult to understand which parameters of the university's activity are significant for its competitiveness. The changes that are taking place in the education system of most states, especially with the onset of the COVID-19 pandemic, have significantly changed the field that can be relied upon when assessing the competitiveness of universities. Classical assessment approaches need to consider all aspects of educational activity and the dynamics of transformation of the university's informational, educational environment.

To increase the efficiency of the university's educational activity and increase its competitiveness in the conditions of digital transformation, it is necessary to qualitatively build an informational university environment, in particular in terms of educational activity, and to build methods and models for assessing competitiveness at a new conceptual level. The construction of a system that would automate these processes will allow the manager of a higher education

institution or the head of a department to systematically analyze educational activities, identify work components that have deficiencies and correct them.

The idea of creating methods and models for evaluating the competitiveness of educational activities of universities in the conditions of digital transformation and taking into account the dynamics of changes in the informational university environment is a new vision that expands theoretical and practical knowledge in this direction.

Thus, this dissertation solves an important task, namely, the development of methods and models for evaluating the competitiveness of educational activities of universities in the conditions of digital transformation, taking into account the dynamics of the informational university environment (scientific component). It also solves the critical task of automating the evaluation of the competitiveness of educational activities of universities, which is based on the application of web technologies (practical component).

**The object of the study** is the processes related to the evaluation of the competitiveness of educational activities of universities.

**The subject of the study** is the methods and models of evaluating the competitiveness of educational activities of universities in the conditions of digital transformation.

**Research methods.** The conducted research is based on knowledge presentation and processing methods, evaluation methods, monitoring of university activities, and object-oriented programming.

**The purpose of the study** is to increase the efficiency of educational activities of universities by developing methods and models for evaluating the competitiveness of educational activities of universities in the conditions of digital transformation to increase the efficiency of their activities.

**The scientific novelty of the obtained results:**

- for the first time, the method of evaluating the competitiveness of universities in terms of their educational activity in dynamics is described, which takes into account the changes that occur at the level of the university environment

and is characterized by the possibility of a comprehensive assessment of the university's development potential;

- the methods of forming information environments of universities and collecting parameters about the educational activity of universities, which are used to assess their competitiveness and differ in that they take into account the entire spectrum of educational activity that changes in the conditions of digital transformation, have been improved;

- improved the principles of collecting information about the activities of universities to assess their competitiveness, the structural model of the implementation of the system for evaluating the competitiveness of educational activities of universities, which is based on the use of Web technologies and allows to automatically take into account the change in the parameters of the information university environment, which is characteristic of the conditions of digital transformation.

- the conceptual presentation of the process of evaluating the competitiveness of the educational activity of universities in dynamics in the conditions of digital transformation, which takes into account the peculiarities of the construction and composition of informational university environments and allows expanding theoretical and practical opportunities to increase the effectiveness of educational activities.

**The first chapter** describes the features of using system-dynamic modeling of the educational activity of universities and identifies the key aspects that affect the positive dynamics of the university's development from the point of view of system dynamics. It is indicated that the use and improvement of the project management methodology applied to the educational activities of universities is a guarantee of their progressive development and increased competitiveness, especially in the conditions of digital transformation, which the education system is currently experiencing worldwide.

The chapter shows that the evaluation of the competitiveness of universities is a complex and multidimensional process, which includes the analysis of various

aspects of the activity of educational institutions. The main methods and criteria for evaluating the competitiveness of universities are indicated, which include the calculation of academic indicators, indicators of the quality of the educational process, research activities of the university and international activities, evaluation of the university infrastructure and resources, as well as the effectiveness of management and reporting in general. A review of these indicators is necessary for further calculations and the construction of methods for evaluating the competitiveness of universities.

An analysis of modern provisions in the management of educational projects of the university was carried out. It was revealed that the existing practice of determining the quality of educational activities of educational institutions, as a rule, is focused on evaluating students' success in learning knowledge. However, for a full-fledged and comprehensive assessment of the competitiveness of universities, all components that affect this activity are essential. The need for a comprehensive study of them is especially evident in the conditions of digital transformation. Accordingly, the relevance of developing methods and models for evaluating the competitiveness of universities is confirmed.

**In the second chapter**, it is determined that the educational activity of the university is complex in both the educational component (quality of teaching and methodical materials, etc.) and scientific research (publication activity, project-research activity). The section describes a multiple model of presenting data on the educational activity of universities in terms of the publishing activity of scientific and pedagogical workers. A data presentation scheme has been formed: university, university employees, university events, etc. The described model considers and formalizes aspects of the university's educational activity, which is the basis for calculating competitiveness assessments and is distinguished by a systematic approach to building dependencies and connections necessary for calculating parameters.

A method of calculating the university's competitiveness was developed, which is calculated based on the number of criteria that the university satisfies. The

requirements of the ministry form the criteria. They are intended for the university's accreditation as an educational structure. Still, the list and meaning of the criteria can be set by the organization that evaluates the university's educational activities. The section also contains formulas for calculating the university's competitiveness in dynamics, defined as the ratio of the number of criteria that received a positive assessment to those that received a negative assessment  $p$  periods ago. A scale of comparison of universities by level of competitiveness was built and described. A system of parameters that determine the competitiveness of universities has been built and the method of data coverage analysis is described, which can be used for a preliminary assessment of the university's competitiveness and is based on the constructed parameters.

**The third chapter** describes the methods and models for evaluating the competitiveness of educational activities of universities, together with their information environment, which considers several important parameters or indicators of university activity. It is indicated that the university information environment changes over time and this dynamic should also be considered in evaluating the university's competitiveness. Formulas for comprehensive evaluation of the competitiveness of educational activities of universities have been developed. This is important because the evaluation results allow us to highlight those components of the university's activities that need to be improved to increase the recognition and prestige of the educational institution.

**The fourth chapter** describes the software module for evaluating the competitiveness of the educational activities of universities, in particular modules for collecting information about the activities of the university to evaluate its competitiveness, the structural model of the implementation of the system for evaluating the competitiveness of the educational activities of universities using Web technologies, the technology for implementing the Web resource for filling the database data with the parameters of the university's information environment for assessing the competitiveness of its educational activities.

The practical significance of the obtained results is that the developed methods and models make it possible to carry out a comprehensive assessment of the competitiveness of the university's educational activity, which allows comparing universities according to various categories of educational activity and identifying those components of work that need improvement. The obtained tool is essential for local self-government bodies and the state to determine promising funding directions in the activities of universities and university clusters. In the long term, the use of the developed methods and models will positively impact the development of the educational activity of the state as a whole. The main provisions and results of the research were implemented and applied in the activities of Yancheng Polytechnic College.

The results obtained, in both theoretical and practical terms, serve as the basis for further scientific and applied research aimed at improving various aspects of the educational activity of universities. Ensuring the sustainability of the development of universities is at the core of the critical requirements of international systems for monitoring their educational activities.

**Keywords:** educational activity, assessment of competitiveness, project management, mathematical model, educational component, university environment, educational project, monitoring of educational activity.

## **LIST OF PUBLICATIONS OF THE APPLICANT BY PHD THESIS**

### **TOPIC**

#### **Articles in professional publications of Ukraine**

**(included in the list of the Ministry of Education and Science of Ukraine)**

1. **Chen, Jie.** (2019). Simulation modelling of competitiveness of Ukrainian higher educational institution in Zhejiang educational market. Management of Development of Complex Systems, 37, 105 – 110, dx.doi.org\10.6084/m9.figshare.9783110. [category «B»]  
<https://urss.knuba.edu.ua/files/zbirnyk-37/18.pdf>

2. **Chen, Jie.** (2019). Development of the model of the mutual influence of the factors of competitiveness of the university in the Yanchen cluster. *Management of Development of Complex Systems*, 38, 117 – 124, dx.doi.org\10.6084/m9.figshare.9788570. [category «B»]  
[https://urss.knuba.edu.ua/files/zbirnyk-38/20\\_0.pdf](https://urss.knuba.edu.ua/files/zbirnyk-38/20_0.pdf)
3. **Chen, Jie.** (2020). Comparison of the competitiveness of the international educational programs of Weihai Vocational College and Shanghai Transport University. *Management of Development of Complex Systems*, 41,141–146, dx.doi.org\10.32347/2412-9933.2020.41.141-146 [category «B»]  
<http://mdcs.knuba.edu.ua/article/view/203821/203570>
4. **Chen, Jie.** (2023). Parameters of monitoring the competitiveness of higher education institutions. *Management of Development of Complex Systems*,55, 123–127, <https://doi.org/10.32347/2412-9933.2023.55.123-127>  
<http://mdcs.knuba.edu.ua/article/view/291115>

#### **Articles in professional publications of Ukraine**

(not included in the list of the Ministry of Education and Science of  
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1. **Chen, Jie.** (2020). Development of a model of mutual influence of university competitiveness factors in the Yancheng Cluster. *Science Journal Innovation Technologies Transfer*. 40-347. <http://www.iamsti.org.ua/sjitt-2020-4-09/>

#### **Approbation works**

1. **Chen, Jie, Ryzhkov, O.** (2021). Calculation of the competitiveness factors of international educational programs of Shanghai Transport University and Weihai Vocational College. *2021 IEEE International Conference on Smart Information Systems and Technologies (SIST)*, Nur-Sultan, Kazakhstan, 2021, pp. 1-5, doi: 10.1109/SIST50301.2021.9465969. [**Scopus, Web of Science**]

2. **Jie Chen.** (2018). Project management for education in accordance with globalization process. *V international scientific and practical conference "Information technologies and interactions"*, 57-58.
3. **Chen Jie.** (2020). Comparison of the competitiveness of international college and university educational programs (China). *Conference «Management of projects in the development of society»*, 141-142. [In Ukrainian]
4. **Chen, Jie.** (2019). Modelling of foreign university in chinese educational market. *I international scientific-practical conference, IMTSK-2019 (Information Modeling Technologies, Systems and Complexes)*, 2019, 113-114.
5. **Chen, Jie.** (2020). Competitiveness modeling of foreign university in Zhejiang educational market. *Seventh international scientific-practical conference «Management of the development of technologies» Topic: "Information technology development of educational content» Kyiv, 25 – 26 March 2020*, 12-13.

## **АНОТАЦІЯ**

**Чен Цзе. Моделі та методи оцінювання конкурентоспроможності освітньої діяльності університетів в умовах цифрової трансформації. – Кваліфікаційна наукова праця на правах рукопису.**

Дисертація на здобуття наукового ступеня доктора філософії за спеціальністю 122 «Комп'ютерні науки» – Київський національний університет імені Тараса Шевченка, Київ, 2023.

**Зміст анотації.** Дисертація присвячена побудові моделей та методів оцінювання конкурентоспроможності освітньої діяльності університетів в умовах цифрової трансформації. Побудовані моделі та методи можуть бути застосовані для вирішення актуального науково-практичного завдання підвищення конкурентоспроможності університетів, враховуючи особливості освітньої діяльності.

Розвиток держави, поява нових інновацій, ідей не в останню чергу забезпечується ефективною діяльністю університетів. Зараз, в умовах цифрової трансформації, з'являються багато факторів, які здійснюють вплив

на цю діяльність. Велика кількість параметрів складно виміряти, вони мають різні типи даних, крім того складно зрозуміти, які з параметрів діяльності університету значимі для його конкурентоспроможності. Ті зміни, які відбуваються з системою освіти більшості держав, особливо з початком пандемії COVID-19, значно змінило поле, на яке можна спиратися при оцінювання конкурентоспроможності університетів. Класичні підходи оцінювання не враховують всіх аспектів освітньої діяльності та не враховують динаміку трансформації інформаційного освітнього середовища університету.

Для підвищення ефективності освітньої діяльності університету і підвищення його конкурентоспроможності в умовах цифрової трансформації потрібно якісно побудувати інформаційне університетське середовище, зокрема в частині освітньої діяльності та побудувати методи і моделі оцінювання конкурентоспроможності на новому концептуальному рівні. Побудова системи, яка б автоматизувала ці процеси дозволить менеджеру закладу вищої освіти або керівнику департаменту системно проаналізувати освітню діяльність, виділити складники роботи, які мають недоліки та виправити їх.

Ідея створення методів та моделей оцінювання конкурентоспроможності освітньої діяльності університетів в умовах цифрової трансформації та враховуючи динаміку змін інформаційного університетського середовища є новим баченням, що розширяє теоретичні та практичні знання в цьому напрямку.

Таким чином, в даній дисертаційній роботі вирішується важливе завдання, а саме: розроблення методів та моделей оцінювання конкурентоспроможності освітньої діяльності університетів в умовах цифрової трансформації, що враховують динаміку інформаційного університетського середовища (наукова складова). Також вирішується важлива задача автоматизації оцінювання конкурентоспроможності освітньої

діяльності університетів, що заснована на застосуванні web-технологій (практична складова).

**Об'єктом дослідження** є процеси, які пов'язані з оцінюванням конкурентоспроможності освітньої діяльності університетів.

**Предметом дослідження** є методи та моделі оцінювання конкурентоспроможності освітньої діяльності університетів в умовах цифрової трансформації.

**Методи дослідження.** Проведені дослідження базуються на методах представлення і обробки знань, методах оцінювання, моніторингу діяльності університетів, об'єктно-орієнтованого програмування.

**Метою дослідження** є підвищення ефективності освітньої діяльності університетів за рахунок розроблення методів та моделей оцінювання конкурентоспроможності освітньої діяльності університетів в умовах цифрової трансформації для підвищення ефективності їх діяльності.

**Наукова новизна отриманих результатів:**

- вперше описано метод оцінювання конкурентоспроможності університетів в частині їх освітньої діяльності в динаміці, що враховує зміни, які відбуваються на рівні університетського середовища і відрізняється можливістю комплексного оцінювання потенціалу розвитку університету;
- удосконалено методи формування інформаційних середовищ університетів та збору параметрів про освітню діяльність університетів, які використовуються для оцінювання їх конкурентоздатності і відрізняються тим, що враховують весь спектр освітньої діяльності, що змінюється в умовах цифрової трансформації;
- удосконалено принципи збору інформації про діяльність університетів з метою оцінювання їх конкурентоспроможності, структурну модель реалізації системи оцінювання конкурентоздатності освітньої діяльності університетів, що базується на використанні Web-технологій і дозволяє автоматизовано враховувати зміну параметрів інформаційного

університетського середовища, що характерне для умов цифрової трансформації.

- отримало подальший розвиток концептуального представлення процесу оцінювання конкурентоспроможності освітньої діяльності університетів в динаміці та в умовах цифрової трансформації, що враховує особливості побудови та склад інформаційних університетських середовищ і дозволяє розширити теоретичні та практичні можливості для підвищення ефективності освітньої діяльності.

У першому розділі надано опис особливостей використання та системно-динамічного моделювання освітньої діяльності університетів, визначено ключові аспекти, які впливають на позитивну динаміку розвитку університету з точки зору системної динаміки. Вказано, що використання та удосконалення методології управління проектами в застосуванні до освітньої діяльності університетів є запорукою їх поступального розвитку та підвищення конкурентоздатності, особливо в умовах цифрової трансформації, яку зараз переживає система освіти в усьому світі.

В розділі показано, що оцінювання конкурентоспроможності університетів є складним і багатовимірним процесом, який включає в себе аналіз різних аспектів діяльності навчальних закладів. Вказані основні методи та критеріїв для оцінювання конкурентоспроможності університетів, що включають розрахунок академічних показників, показників якості освітнього процесу, науково-дослідної діяльності університету та міжнародної діяльності, оцінювання інфраструктури університету та ресурсів, а також ефективності управління та звітності в цілому. Огляд цих показників необхідний для подальших розрахунків та побудови методів оцінювання конкурентоспроможності університетів.

Проведено аналіз сучасних положень в управлінні освітніми проектами університету. Виявлено, що існуюча практика визначення якості освітньої діяльності навчальних закладів, як правило, зосереджена на оцінюванні успішності студентів у засвоєнні знань. Проте для повноцінного і

комплексного оцінювання конкурентоздатності університетів важливою є всі складники, які впливають на цю діяльність. Особливо необхідність комплексного їх дослідження проявляється в умовах цифрової трансформації. Відповідно підтверджується актуальність розробки методів та моделей оцінювання конкурентоздатності університетів.

**В другому розділі** визначено, що освітня діяльність університету є комплексом як навчальної складової (якість викладання та методичних матеріалів тощо), так і науково-дослідної (публікаційна активність, проектно-дослідна діяльність). В розділі описана множинна модель представлення даних про освітню діяльність університетів в частині публікаційної активності науково-педагогічних працівників. Сформована схема представлення даних: університет, співробітник університету, університетські заходи тощо. Представлена модель враховує і формалізує аспекти освітньої діяльності університету, що є основою для розрахунку оцінок конкурентоздатності та вирізняється системним підходом до побудови залежностей та зв'язків необхідних для розрахунку параметрів.

Побудовано метод розрахунку конкурентоздатності університету, що розраховується за кількістю критеріїв, які університет задовольняє. Критерії формуються згідно з вимогами міністерства і призначені для акредитації університету, як освітньої структури в цілому. Проте перелік та значення критеріїв може задаватися організацією, яка проводить оцінку освітньої діяльності університету. Також у розділі побудовано формули для розрахунку конкурентоспроможності університету в динаміці, що визначаються як відношення кількості критеріїв, які отримали позитивну оцінку, до кількості критеріїв, які отримали негативну оцінку. Побудовано та надано опис шкали порівняння університетів за рівнем конкурентоздатності. Побудовано систему параметрів, які визначають конкурентоздатність університетів та надано опис методу *data coverage analysis*, який може бути використано для попередньої оцінки конкурентоздатності університету, що базується на побудованих параметрах.

**В третьому розділі** описано методи та моделі оцінювання конкурентоздатності освітньої діяльності університетів, разом з їх інформаційним середовищем, що враховує ряд важливих параметрів або індикаторів діяльності університету. Вказано, що університетське інформаційне середовище змінюється з часом і цю динаміку також потрібно враховувати в оцінці конкурентоздатності університету. Побудовано формули для комплексного оцінювання конкурентоздатності освітньої діяльності університетів. Це важливо, оскільки результати оцінювання дозволяють виділити ті складові діяльності університету, які необхідно покращити, щоб підвищити впізнаваність та престижність навчального закладу.

**У четвертому розділі** надано опис розробленого програмного забезпечення (модуль) для оцінювання конкурентоздатності освітньої діяльності університетів, зокрема модулі для збору інформації про діяльність університету з метою оцінювання його конкурентоздатності, структурна модель реалізації системи оцінювання конкурентоздатності освітньої діяльності університетів з використанням Web-технологій, технологія реалізації Web-ресурсу для наповнення бази даних з параметрами інформаційного середовища університету для оцінювання конкурентоздатності його освітньої діяльності тощо.

**Практичне значення одержаних результатів** полягає у тому, що розроблені методи та моделі дозволяють провести комплексну оцінку конкурентозданості освітньої діяльності університету, що дозволяє порівнювати університети за різними категоріями освітньої діяльності, визначати ті складові роботи, які потребують покращення. Отриманий інструмент є важливим з практичної точки зору для органів місцевого самоврядування та держави в частині визначення перспективних напрямків фінансування діяльності університетів, а також університетських кластерів. В довготривалій перспективі використання розроблених методів та моделей дасть позитивний вплив на розвиток освітньої діяльності держави в цілому.

Основні положення та результати дослідження впроваджено та застосовано в діяльності Яньченського політехнічного коледжу.

Отримані результати, як у теоретичному, так і практичному плані, служать основою для подальших науково-прикладних досліджень, спрямованих на удосконалення та покращення різних аспектів освітньої діяльності університетів. Забезпечення сталості розвитку університетів є в основі ключових вимог міжнародних систем моніторингу освітньої діяльності університетів.

**Ключові слова:** освітня діяльність, оцінювання конкурентоздатності, управління проєктами, математична модель, освітня компонента, університетське середовище, освітній проєкт, моніторинг освітньої діяльності.

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## INTRODUCTION

The development of the state and the emergence of new innovations and ideas are not least ensured by the practical activity of universities. Now, in the conditions of digital transformation, many factors influence this activity. A large number of parameters are difficult to measure, they have different types of data, in addition, it is difficult to understand which parameters of the university's activity are significant for its competitiveness. The changes that are taking place in the education system of most states, especially with the onset of the COVID-19 pandemic, have significantly changed the field that can be relied upon when assessing the competitiveness of universities. Classical assessment approaches need to consider all aspects of educational activity and the dynamics of transformation of the university's informational, educational environment.

In order to increase the efficiency of the university's educational activity and increase its competitiveness in the conditions of digital transformation, it is necessary to qualitatively build an informational university environment, in particular in terms of educational activity, and to build methods and models for assessing competitiveness at a new conceptual level. The construction of a system that would automate these processes will allow the manager of a higher education institution or the head of a department to systematically analyze educational activities, identify work components that have deficiencies and correct them.

The idea of creating methods and models for evaluating the competitiveness of educational activities of universities in the conditions of digital transformation and taking into account the dynamics of changes in the informational university environment is a new vision that expands theoretical and practical knowledge in this direction.

Thus, this dissertation solves an important task, namely, the development of methods and models for evaluating the competitiveness of educational activities of universities in the conditions of digital transformation, taking into account the dynamics of the informational university environment (scientific component). It

also solves the critical task of automating the evaluation of the competitiveness of educational activities of universities, which is based on the application of web technologies (practical component).

The dissertation work was carried out at the Faculty of Information Technologies of Taras Shevchenko National University of Kyiv following the national strategy for the development of education in Ukraine for 2011-2027 and following the plan of research works of Taras Shevchenko National University of Kyiv, in particular the topic "Information technologies of analysis and forecasting of processes, invariant to the subject area", No. 0123U101621.

**The object of the study** is the processes related to the evaluation of the competitiveness of educational activities of universities.

**The subject of the study** is the methods and models of evaluating the competitiveness of educational activities of universities in the conditions of digital transformation.

**Research methods.** The conducted research is based on knowledge presentation and processing methods, evaluation methods, monitoring of university activities, and object-oriented programming.

**The purpose of the study** is to increase the efficiency of educational activities of universities by developing methods and models for evaluating the competitiveness of educational activities of universities in the conditions of digital transformation to increase the efficiency of their activities.

To achieve the goal, the following tasks must be solved:

1. To analyze methods and technologies for evaluating the competitiveness of universities in the conditions of digital transformation, to consider the main methods and criteria for evaluating the competitiveness of universities, which include the calculation of academic indicators, indicators of the quality of the educational process, scientific research activities of the university and international activities, evaluation of university infrastructure and resources, as well as the effectiveness of management and reporting in general.

2. To build methods for the formation of information environments of universities and the collection of parameters about the educational activity of universities, which are used to assess their competitiveness

3. To build a method of evaluating the competitiveness of universities in terms of their educational activity in dynamics, which takes into account the changes occurring at the level of the university environment.

4. To describe the principles of collecting information about the activities of universities to evaluate their competitiveness, the structural model of the implementation of the system for evaluating the competitiveness of universities' educational activities is based on the use of Web technologies.

5. To describe the conceptual representation of the process of evaluating the competitiveness of educational activities of universities in dynamics in the conditions of digital transformation.

**The scientific novelty of the obtained results:**

- for the first time, the method of evaluating the competitiveness of universities in terms of their educational activity in dynamics is described, which takes into account the changes that occur at the level of the university environment and is characterized by the possibility of a comprehensive assessment of the university's development potential;

- the methods of forming information environments of universities and collecting parameters about the educational activity of universities, which are used to assess their competitiveness and differ in that they take into account the entire spectrum of educational activity that changes in the conditions of digital transformation, have been improved;

- improved the principles of collecting information about the activities of universities to assess their competitiveness, the structural model of the implementation of the system for evaluating the competitiveness of educational activities of universities, which is based on the use of Web technologies and allows to automatically take into account the change in the parameters of the information

university environment, which is characteristic of the conditions of digital transformation.

- the conceptual representation of the process of evaluating the competitiveness of the educational activity of universities in the context of digital transformation was further developed, which takes into account the peculiarities of the construction and composition of informational university environments and allows the expansion of theoretical and practical possibilities for increasing the efficiency of educational activity.

The paper describes the features of using system-dynamic modeling of the educational activity of universities and identifies the key aspects that influence the positive dynamics of the university's development from the point of view of system dynamics. It is indicated that the use and improvement of the project management methodology applied to the educational activities of universities is a guarantee of their progressive development and increased competitiveness, especially in the conditions of digital transformation, which the education system is currently experiencing worldwide. The first chapter shows that the evaluation of the competitiveness of universities is a complex and multidimensional process, which includes the analysis of various aspects of the activity of educational institutions. The main methods and criteria for evaluating the competitiveness of universities are indicated, which include the calculation of academic indicators, indicators of the quality of the educational process, research activities of the university and international activities, evaluation of the university infrastructure and resources, as well as the effectiveness of management and reporting in general. A review of these indicators is necessary for further calculations and the construction of methods for evaluating the competitiveness of universities.

An analysis of modern provisions in the management of educational projects of the university was carried out. It was revealed that the existing practice of determining the quality of educational activities of educational institutions, as a rule, is focused on evaluating students' success in learning knowledge. However,

for a full-fledged and comprehensive assessment of the competitiveness of universities, all components that affect this activity are essential. The need for a comprehensive study of them is especially evident in the conditions of digital transformation. Accordingly, the relevance of developing methods and models for evaluating the competitiveness of universities is confirmed.

In the second chapter, it is determined that the educational activity of the university is complex in both the educational component (quality of teaching and methodical materials, etc.) and scientific research (publication activity, project-research activity). The section describes a multiple model of presenting data on the educational activity of universities in terms of the publishing activity of scientific and pedagogical workers. A data presentation scheme has been formed: university, university employees, university events, etc. The described model considers and formalizes aspects of the university's educational activity, which is the basis for calculating competitiveness assessments and is distinguished by a systematic approach to building dependencies and connections necessary for calculating parameters.

A method of calculating the university's competitiveness was developed, which is calculated based on the number of criteria that the university satisfies. The requirements of the ministry form the criteria. They are intended for the university's accreditation as an educational structure. Still, the list and meaning of the criteria can be set by the organization that evaluates the university's educational activities. The section also contains formulas for calculating the university's competitiveness in dynamics, defined as the ratio of the number of criteria that received a positive assessment to those that received a negative assessment  $p$  periods ago. A scale of comparison of universities by level of competitiveness was built and described. A system of parameters that determine the competitiveness of universities has been built, and the method of data coverage analysis is described, which can be used for a preliminary assessment of the university's competitiveness and is based on the constructed parameters.

The third section describes the methods and models for evaluating the competitiveness of educational activities of universities, together with their information environment, which considers several important parameters or indicators of university activity. It is indicated that the university information environment changes over time, and this dynamic should also be considered in evaluating the university's competitiveness. Formulas for comprehensive evaluation of the competitiveness of educational activities of universities have been developed. This is important because the evaluation results highlight those components of the university's activities that need to be improved to increase the recognition and prestige of the educational institution.

The fourth chapter describes the software module for evaluating the competitiveness of the educational activities of universities, in particular modules for collecting information about the activities of the university to evaluate its competitiveness, the structural model of the implementation of the system for evaluating the competitiveness of the educational activities of universities using Web technologies, the technology for implementing the Web resource for filling the database data with the parameters of the university's information environment for assessing the competitiveness of its educational activities.

The practical significance of the results obtained in the dissertation is that:

1. The developed methods and models make it possible to carry out a comprehensive assessment of the competitiveness of the educational activity of the university, which allows comparing universities according to various categories of educational activity and identifying those components of work that need improvement.

2. The resulting tool is practically essential for local self-government bodies and the state in terms of determining promising funding directions in the activities of universities and university clusters.

3. In the long term, the use of the developed methods and models will positively impact the development of educational activities of the state as a whole.

4. The main provisions and results of the research were implemented and applied in the activities of Yancheng Polytechnic College.

The obtained results, theoretically and practically, serve as the basis for further scientific and applied research aimed at improving and ensuring the sustainable development of universities and increasing their competitiveness. The author published the work's main results in the following publications [1-10].

**Personal contribution of the acquirer.** The applicant personally received the main provisions and results of the dissertation work. The work [1] describes the process of modeling and evaluating competitiveness in education using the example of the Zhejiang educational market. The work [2] describes the development of the model of the mutual influence of the factors of competitiveness of the university in the Yanchen cluster. The work [3] describes the features of evaluating the competitiveness of educational activities, using the example of the international educational programs of Weihai Vocational College and Shanghai Transport University. The work [4] describes the list of parameters of the educational activity of the university, which are necessary for building the university's information environment. The work [5] describes developing a model of the mutual influence of university competitiveness factors in the Yancheng Cluster. The materials from international conferences were also published, in which the provisions of the dissertation work are revealed in more detail [6-10]. The work [6] was published in the edition indexed in the Scopus scientometric database.

Approval of the results of the dissertation. The main results of the work were reported, discussed, and received a positive evaluation at international conferences "Information technologies and interactions", Kyiv (2018), "Project Management in the Development of Society", Kyiv (2019), "Information Modeling Technologies , Systems and Complexes", Chernivtsi (2019), "Technology Development Management", Kyiv (2020), IEEE conference "Smart Information Systems and Technologies" (SIST-2021), Astana, Republic of Kazakhstan.

**Publications.** Based on the dissertation materials, 10 scientific works have been published, including: 4 scientific articles in specialized publications of Ukraine, 1 article in a publication that is not included in the list of the Ministry of Education and Culture, 5 materials of international conferences, one of them in a publication that is indexed by the Scopus database. The main results of the work were obtained by the author personally. Of the scientific works published in co-authorship, the dissertation research describes those provisions resulting from the author's work.

**Structure and scope of work.** The dissertation consists of an introduction, four chapters, chapter conclusions, main conclusions, a list of references and appendices. The total volume of the dissertation is 141 pages, including 14 figures, 9 tables, a bibliography of 101 titles and 2 appendices.

# **CHAPTER 1. ANALYSIS OF THE CURRENT STATE OF COMPETITIVENESS ASSESSMENT OF THE EDUCATIONAL ACTIVITIES OF UNIVERSITIES**

## **1.1. System-dynamic modeling of educational activity as a project in the activities of universities**

Digital transformation in education refers to the integration and use of digital technologies to enhance and revolutionize teaching and learning processes. It involves leveraging digital tools, resources, and platforms to improve educational outcomes, streamline administrative tasks, and create a more efficient and engaging learning environment. Digital transformation in education encompasses a wide range of initiatives and changes, including:

1. Incorporating digital tools and devices into classrooms to support teaching and learning. This may include interactive whiteboards, tablets, laptops, and educational software.

2. Implementing virtual learning environments, learning management systems (LMS), and online platforms to facilitate remote and flexible learning opportunities. This allows students to access educational resources and interact with instructors outside of traditional classroom settings.

3. Utilizing data analytics and educational technology to track and analyze student performance, enabling personalized learning experiences. Teachers can use data to identify areas where students may need additional support and tailor their instruction accordingly.

4. Promoting collaborative learning through digital tools and platforms that enable students to work together on projects, share resources, and communicate effectively.

5. Combining traditional face-to-face instruction with online learning experiences. This approach allows for greater flexibility and customization in learning, catering to individual student needs.

6. Leveraging digital tools for more effective assessment and timely feedback. This may include online quizzes, automated grading systems, and interactive assessment methods.

7. Streamlining administrative processes such as enrollment, grading, and communication through the use of digital tools and platforms, reducing administrative burdens on educators.

8. Providing educators with opportunities for ongoing professional development through online courses, webinars, and other digital resources to enhance their digital literacy and teaching skills.

9. Ensuring that digital transformation efforts consider the accessibility needs of all students, including those with disabilities, to create a more inclusive learning environment.

10. Implementing adaptive learning technologies that tailor educational content and experiences based on individual student progress and needs.

Digital transformation in education aims to prepare students for the challenges of the digital age, enhance the quality of education, and provide more equitable access to learning opportunities. It also plays a crucial role in preparing students with the digital skills and literacy required in today's technologically advanced society.

The educational activity of universities includes a wide range of actions and processes aimed at ensuring quality education and training of qualified specialists: students of higher education, students of advanced training courses, etc. It is possible to single out several components of the educational activity of universities which are especially relevant in the conditions of digital transformation. The first component of educational activity concerns training: development and implementation of various academic programs (bachelor's degree, master's degree, doctorate) in various fields of knowledge, conducting lectures, seminars and practical classes for students.

The second component concerns scientific research activities: conducting scientific research and developing new knowledge in various fields. Publication of

research results in scientific journals and conferences. The third component concerns pedagogical activity and includes training qualified teachers and scientists and developing teaching methods and educational materials. The fourth component concerns international cooperation: providing opportunities for students and teachers to participate in international exchanges and implementing joint projects and scientific programs with other universities. It is also possible to highlight individual components of educational activities, such as: cultural and social activities, career counseling and support. All these aspects form the comprehensive educational activity of universities, aimed at deep and comprehensive development of students, as well as contributing to the development of science and society.

Educational activity in universities is a project or a complex of projects with a goal - to develop the university and increase its competitiveness. The university's competitiveness is an essential aspect of its development and success. To be competitive, a university must effectively implement several strategies and practices reflected in various aspects of its activities.

As a set of activities or tasks, projects have a specific goal (scope), which will be completed within certain specifications (requirements), defined start and end dates, have funding limits, and have limits on consumption and/or use of resources [11].

Project management, particularly in educational activities, has proven useful in planning and managing the activities of universities. This is largely because project conditions and performance evolve. This has made the application of system dynamics to project management a productive field for research. Many models have been developed to improve project management, particularly in university management. These models include some of the features of systems and characteristics of system dynamics. For example, basic project models such as the critical path method for phase design and cost control modeling use projected performance gaps (such as budget shortfalls) to allocate funds. More advanced models, such as computational models, are developed in [12]. In some works, the

authors focus on the structure of the model, while others focus on the use of the model and describe the structure of the model only in general terms [13, 14].

In the context of digital transformation in education, project management plays a crucial role in implementing and overseeing various initiatives. Here are some features and considerations specific to project management in the conditions of digital transformation in education:

1. Clearly define the goals of digital integration in education, whether it's the implementation of a learning management system (LMS), adoption of online collaboration tools, or any other technological initiative. Outline the scope of the project, identifying the specific areas of education that will be impacted by digital transformation.

2. Foster collaboration and communication among stakeholders, including educators, administrators, IT professionals, and students. Establish mechanisms for obtaining regular feedback from stakeholders to ensure their needs are considered throughout the project.

3. Conduct a thorough assessment of the existing technology infrastructure to identify strengths, weaknesses, and areas that need improvement. Plan for scalability to accommodate future growth and changes in technology requirements.

4. Provide training and support for educators to enhance their digital literacy and teaching skills. Develop a comprehensive budget that includes costs for technology acquisition, training, and ongoing maintenance.

5. Embrace an agile project management approach to adapt to changes and incorporate feedback quickly. Break down the project into smaller, manageable phases with iterative development and testing.

6. Ensure compliance with data security and privacy regulations to protect sensitive student information. Implement robust user access controls to safeguard digital educational resources.

7. Integrate collaboration tools and communication platforms to facilitate seamless interaction among project team members. Utilize project management dashboards for real-time tracking of progress, milestones, and potential issues.

8. Develop and implement change management strategies, including training programs for educators and staff to embrace new digital tools. Establish effective communication plans to inform stakeholders about changes, updates, and the benefits of digital transformation.

9. Define and monitor key performance indicators to assess the success and impact of the digital transformation project. Implement a continuous improvement process based on feedback and evaluation results.

10. Prioritize a user-centric design for digital tools to ensure a positive and intuitive user experience. Ensure that digital resources are accessible to all students, including those with diverse learning needs.

When modeling the project, in particular, in the activities of universities, the following aspects can be distinguished:

1. Features of the project. Projects almost always consist of a set of tasks that are performed in parallel and series. Thus, the main feature of all dynamic project modeling systems represents the development tasks or work packages they perform throughout the project.

2. Recycling cycle. System dynamics has many canonical structures used in most specific models' dynamics. In WIP inventory (work-in-process inventory), the structure in supply lines [15] and urban dynamics [16] are examples. The scheme of the recycling cycle is described in Figure 1.1. Works [17 - 19] describe more details about this cycle.

3. Feedback control: Modeling, analysis, and control improvement of dynamic systems is the goal of applying system dynamics. Since project managers strive to complete the tasks on time, within the budget, with high quality, and with the satisfaction of all requirements, the simulation of feedback control cycles is carried out. This is inherent in the educational activities of universities. The

purpose of such cycles is to reduce the gap between project executors and customers (Fig. 1.2.) [20].

4. Ripple and Knock-on effects: the politics of resistance and random effects are the main explanations used in system dynamics for many adverse situations (Fig. 1.3., Fig. 1.4.). These effects are mainly manifested in the process of digital transformation, which is characteristic of all universities and the entire education system, which manifested itself in particular during the pandemic.

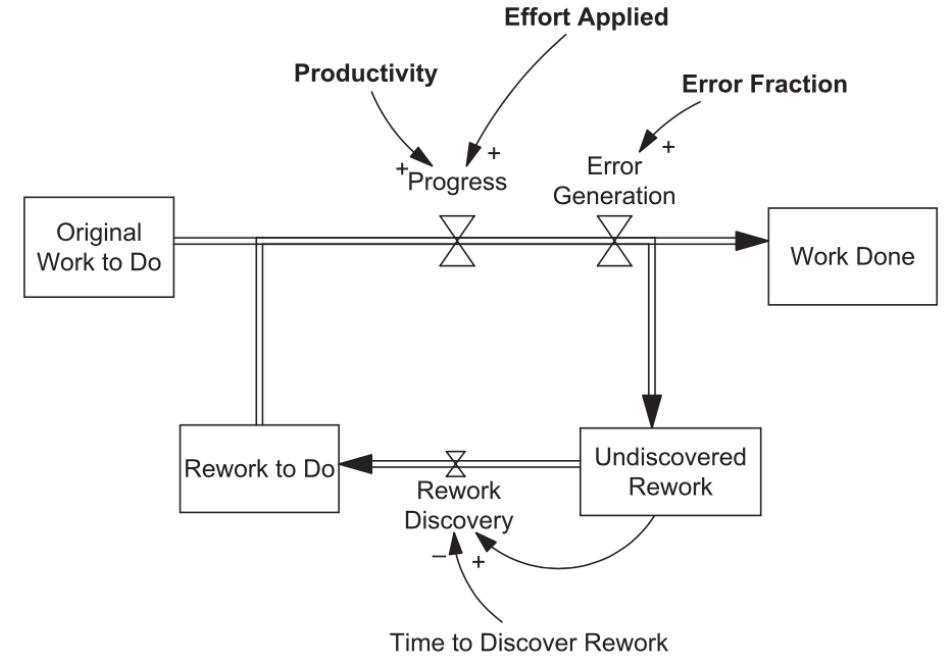


Figure 1.1. – General scheme of the recycling cycle.

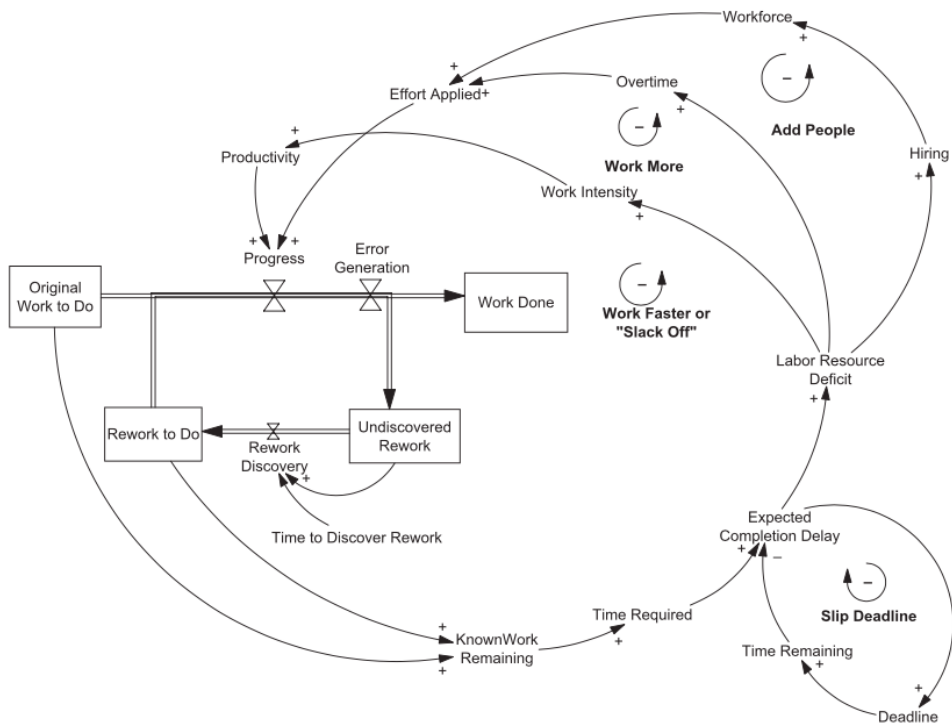


Figure 1.2. – Managing feedback loops to achieve the target schedule

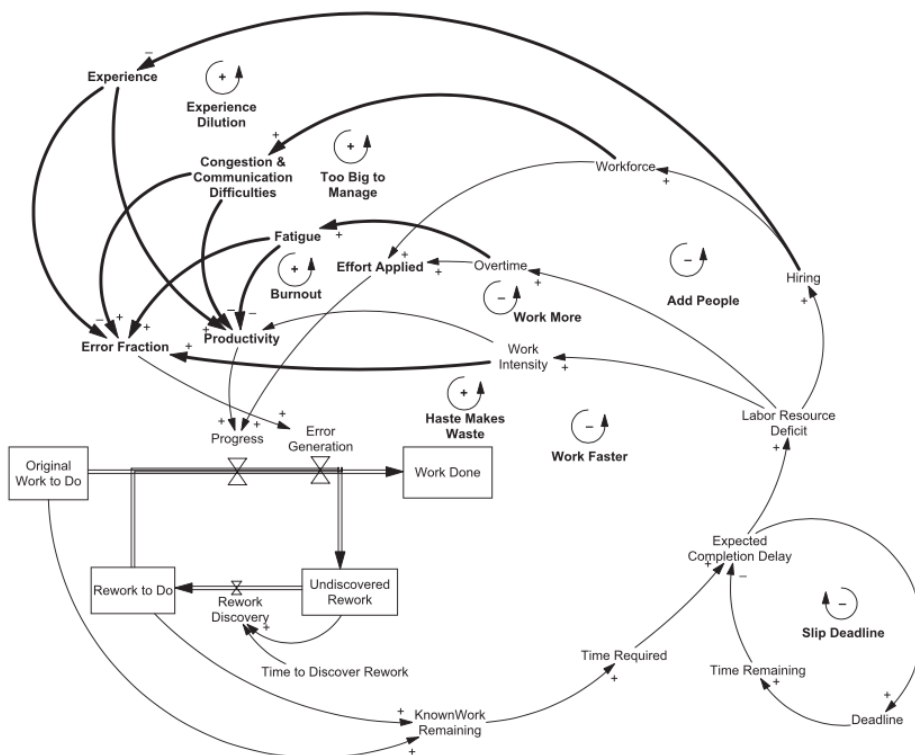


Figure 1.3. – Resistance factors through the ripple effect, recycling and feedback control to improve university competitiveness ratings



Thus, the elements of system dynamics can be useful for managing and evaluating the competitiveness of educational activities of universities [24-33], in particular in the conditions of digital transformation.

## **1.2. Methods of evaluating the competitiveness of universities based on the project approach**

The effective functioning of higher education is the key to training high-level specialists. These specialists are the basis for ensuring the rapid development of society promoting development and innovation in various social spheres. High-quality higher education plays a significant role in increasing the country's and society's overall competitiveness. Therefore, the issue of evaluating the quality of higher education and the productivity of training specialists has always been relevant for research [34-37]. For evaluation, educational environments are created where universities function and interact with other universities within the framework of joint scientific and educational projects. Multi-criteria methods for selecting the best higher education institutions and scientists from among their employees are also being created [38-40].

Monitoring competitiveness is a higher-level task than simply evaluating the effectiveness of education. After all, the competition between higher education institutions for leadership in this field is an incentive for the training of high-quality specialists. In turn, this goal has scaled to the level of the state and the corresponding region. This is because trained specialists increase the state's competitiveness in the future. That is, monitoring and increasing the competitiveness of higher education institutions has excellent academic significance [41, 42].

The work [43] describes measures and strategies for improving the educational competitiveness of colleges and universities at the regional level. At the same time, these measures include the internationalization of scientific and educational activities. The work [44] identified the competitive advantages of

higher education in China and proposed appropriate improvement strategies. Methods of increasing the competitiveness of higher education in cross-border regions based on an education audit are described in [45]. It was pointed out that audit is the only way to increase the competitiveness of higher education. In work [46], the issue of management of competencies and innovations for transforming higher education. In [47], an analysis of the competitiveness of higher education, a model for creating a competitiveness index, was carried out. Then, based on this model and the corresponding index, a comparison of the competitiveness of China's higher education with other countries was made. The work [48] analyzed the impact of reputation in higher education on competitiveness. In [49], a fuzzy estimation method based on resource allocation is discussed. The work [50] analyzes the key factors affecting the educational competitiveness.

It should be noted that various higher education institutions provide training in various specialties (IT, humanities, mathematics, physics, etc.). All these directions can be completely heterogeneous, so it isn't easy to conceptually approach the monitoring of the competitiveness of such universities. There is also a different understanding of competitiveness. Scientists include various indicators in it. In general, for assessing competitors, opportunities are often traditionally distinguished: assessment of educational activity, scientific activity, international activity, financial activity, graduates' employment as an assessment of their qualification level, and existing university infrastructure [51].

However, the indicated list of indicators could be better. Due to the heterogeneity of international, scientific, and educational activities in various fields of knowledge, it is challenging to adequately evaluate universities that provide educational services in various fields. It is necessary to develop a system of parameters that influence the increase in the competitiveness of universities, especially in the conditions of digital transformation.

Evaluating the competitiveness of universities is a complex and multidimensional process that includes the analysis of various aspects of the activity of educational institutions. There are several methods and criteria for

evaluating the competitiveness of universities. Here are some of them:

1. Academic performance. Using national and international rankings such as QS World University Rankings, Times Higher Education (THE) World University Rankings, Academic Ranking of World Universities (ARWU) to get an overall picture of competitiveness. Analysis of the number of scientific publications, their influence and citations.

2. Quality of the educational process. The success rate of entrants, the rating of applicants, the level of graduates and their achievements on the labor market. Qualification, scientific degree, teaching experience and other criteria of the teaching staff.

3. Scientific and research activity. The level of the university's involvement in research work, participation in national and international scientific projects. Number of patents, developments and their practical value.

4. International cooperation. The level of international mobility. Development of a network of academic partnerships.

5. Infrastructure and resources. Level of funding, availability of grants and sponsorship. Quality of classrooms, research laboratories and libraries.

6. Reporting and management. The level of transparency, the efficiency of the use of resources, the participation of the university community in decision-making.

### **1.3. Analysis of modern provisions in the management of university educational projects to increase their competitiveness**

Monitoring is a process of systematic observation, control, and data collection about particular objects, phenomena, or processes. The primary purpose of monitoring is to obtain up-to-date information about the state of the object or phenomenon to make informed decisions, detect anomalies in time, respond to them, and improve the control process.

The competitiveness of a higher education institution is the ability of a higher education institution to compete effectively in the market of educational services and gain a particular market share or increase its position relative to other

players in this field, that is, other higher education institutions. Competitiveness is an essential factor for the successful operation of a higher education institution. The competitiveness of a higher education institution is essential for attracting students, ensuring their high-quality education, and preparing them for a successful career.

To organize monitoring of the competitiveness of a higher education institution, it is necessary to collect data on various types of activity of a higher education institution during a specific period and save them for processing. Data should be open, verifiable, transparent, and easy to verify. They should be free from the influence of the subjective factor. This is important to ensure an unbiased assessment of the activities.

The model for monitoring a higher education institution's competitiveness includes several steps and components that help analyze and evaluate the institution's effectiveness in competitive conditions. Here is the general model for monitoring the competitiveness of HEIs:

1. Determination of key performance indicators. These indicators include academic quality, reputation, foreign partnerships, number and quality of students, financial sustainability, etc.

2. Data collection. After collecting a list of key indicators, develop a data collection system for these indicators. This may include analysis of existing data, student surveys, alum surveys, financial statements, etc.

3. Data analysis and evaluation. After the data has been collected, it is necessary to conduct an analysis and evaluation to find out how the institution of higher education compares to its competitors. Determination of strengths and weaknesses of a universities.

4. Setting goals and strategies. Based on the analysis results, setting goals and developing strategies to improve competitiveness is necessary. These goals and strategies should be specific, measurable.

5. Implementation of measures. Implementation of strategies aimed at improving competitiveness. This may include modernization of programs,

improvement of the quality of education, development of marketing campaigns, improvement of financial stability, etc.

6. Monitoring and evaluation of results. Constantly monitor the impact of strategies on the institution's competitiveness. Use the metrics to determine whether you have achieved your goals and adjust your actions accordingly.

7. Reporting and communication. Reporting to stakeholders such as administration, faculty, students, parents, financial sponsors, etc.

8. Adaptation and improvement. Based on the obtained results, it is necessary to make adjustments in the strategy and activities to maintain or improve the competitiveness of the higher education institution.

The process of fundamental economic and social changes, the transition to a market economy and a multi-system economy poses new challenges to management. The movement along the path of strengthening the specialization of management will allow more dynamic changes in the methods of training specialists, taking into account the advanced achievements of science and changes in social needs. Therefore, in order to ensure the effective operation of educational organizations in modern conditions, it is necessary first of all to improve their management systems [52, 53]. Such improvement is related to the need to use modern management methods in the implementation of almost all types of activities, and primarily it concerns the scientific component of educational institutions. Scientific research is the basis for the formation of the professorial staff of the university. The transmission of scientific results of universities into the education system contributes to the formation of highly qualified specialists who receive modern knowledge and the necessary competencies [54].

The world has accumulated considerable experience in improving educational management systems [55-58]. If the differences in management organizations at the level of primary education are insignificant, then at the level of higher education management organizations and national education management organizations, the differences are quite significant.

The formation of the organizational structure of educational institutions is

influenced by four main factors:

- national traditions;
- the general concept of higher education management adopted in this country;
- the scope of professional training and the scope of scientific research at the university;
- autonomy of the university.

Let's consider some key organizational models of management in the educational sphere, which are used in developed countries and can determine the competitiveness of universities. These models can take the form of centralized or decentralized management [59-61]. One of these models is centralized. Education management in countries such as Ukraine, Russia, France, Germany, Sweden and others is characterized by a significant degree of centralization [62-66]. In these countries, all educational institutions are subordinate to the Ministry of Education. State bodies regulate the day-to-day activities of educational institutions, develop educational standards and provide financial support. Usually, universities in such countries have a centralized structure with broad powers for managers at different levels. Decisions, both academic and administrative, are often made at the central level of management.

It is clear that in this case, the implementation of projects related to the external aspects of the educational institution receives support from external management bodies. However, the lack of autonomy of higher educational institutions leads to a lack of authority of the managers of such projects, since the launch of projects that require external financing is complicated by long-term coordination with external financial donors.

The decentralized model of education management differs from the centralized model in countries such as Great Britain, the United States, Denmark, and the Netherlands [67, 68]. In these countries, the central education management bodies are limited to defining the overall development strategy, allocating appropriate financial resources and monitoring the directions and results of the

activities of educational institutions, without interfering in the current activities. Management of day-to-day activities is carried out mainly at the regional and local levels through various intermediate governing bodies as well as specific universities. It is important to note that at the level of a separate educational institution, management is practically decentralized [69].

The main structural units in an educational institution in the system of decentralized management [69] are branches or departments, which have more autonomy and freedom. The heads of these departments act as key officials in the institution's administration system. Decisions made at the departmental level determine the content and direction of the university's activities. The higher levels of the hierarchy only record and approve what is decided at the branch level. However, they use their resource allocation function as leverage.

Let us note a vivid example of a decentralized management system in the education system of Great Britain [69]. It should also be noted that the economic and legal relationship between the state and universities in Canada is complex. A similar, but slightly different version of the decentralized organizational structure of educational institutions exists in the USA [69].

The main barrier to organizational changes in educational institutions is the dominant position of traditional management methods based on hierarchical functional and disciplinary departmentalization of educational and scientific activities [70–72]. In general, it is believed that the hierarchical structure of the university can be improved with the help of changes in the number and reorganization of units, but this cannot lead to significant improvements in organizational relations [73, 74]. However, management development and organizational transformation require a change in structural relations within the organization. This means moving from one type of structure to another. A new organizational type can be both well-known and innovative, created in accordance with a change in the external environment [74].

The main characteristics of the development of the management of educational institutions are the definition of new tasks, revision of the foundations

of management, consideration of the personnel potential of the organization and informatization of decision-making processes [72–74].

Poor management in any field is a major cause of problems, including education. In developed Western countries, it is believed that the system of higher education should have built-in self-regulation and independent management. This involves the transition to selective financing of universities depending on their rating, the development of competitive principles in the field of higher education, and the minimization of the centralized administrative influence of the state on the activities of universities.

The modern development of education is significantly influenced by the demands of society, which is rapidly changing in the conditions of the development of information technologies, the improvement of communications and access to educational information, as well as new types of educational services and products in a globalized world. Modern educational institutions should consider their development as a strategy for creating value for society and the individual on the basis of person-oriented education for the development of abilities, skills and knowledge, and the formation of professional training competencies of graduates.

The existing practice of determining the quality of educational activities of educational institutions, as a rule, is focused on evaluating the success of students in acquiring knowledge. At the same time, the level of assimilation corresponds to the requirements of education standards. In assessing student success, education authorities and users of educational services place different values on end-of-learning assessments and interim assessments that provide continuous feedback to adapt learning to individual student abilities. Intermediate assessment provides information about the current level of knowledge and the degree of their assimilation within the framework of educational activities.

The creation of a quality management system for the scientific and educational activities of educational institutions based on value profiles is becoming an urgent need in the modern development of education in Ukraine.

Currently, there are various international methods for evaluating the activities of higher education institutions, in particular, the QS rating and the Shanghai rating, which take into account different indicators.

The QS rating takes into account the following indicators [75]: index of academic reputation, index of reputation among employers, ratio of the number of teaching staff and students, index of citations of scientific articles by teaching staff in scientometric databases (Scopus) in relation to the number of teaching staff, the share of foreign teachers and students.

The Shanghai ranking [76] takes into account the following indicators: the number of articles published in Nature or Science, the number of cited publications (SCIE and SSCI citation index), the number of professors who received the Nobel or Fields Prize, the number of cited publications, the number of graduates who received the Nobel or The Fields Prize, the ratio of the specified indicators to the number of university personnel.

The site "Osvita.ua" [77] compiled a consolidated rating of Ukrainian universities for 2016, using various national and international ratings, such as "Top-200 Ukraine", "Scopus" and "Webometrics". The methodology "Top-200 Ukraine" [78] takes into account the index of quality of scientific and pedagogical potential, the index of quality of education and the index of international recognition. In particular, innovative activities of universities are taken into account.

The growth of competition between universities for limited resources determines the main factor in the change of the external environment. Recently, there has been a rethinking of society's attitude to work in the educational sphere, which leads to insufficient motivation for teachers of higher educational institutions. Economic crisis phenomena cause a decrease in the demand for specialists, which leads to the limitation of financial support of educational institutions.

A significant decline in the birth rate in Ukraine at the beginning of the 2000s led to a noticeable decrease in the number of potential applicants,

intensifying competition between universities in the domestic market of educational services. Ukraine, participating in the global educational process, also faces growing competition from foreign universities. According to the analytical center CEDOS, in 2016-2017, about 60,000 Ukrainians studied abroad, and this number may increase to 68,000 in the current academic year [79].

In such an environment, project-oriented management of universities becomes important for the development and implementation of long-term measures for the formation and maintenance of competitive advantages in the market of educational services. The management of higher educational institutions most often directs its efforts to the implementation of strategic programs aimed at achieving results in one of the priority areas, namely the improvement of management processes.

The existing system of evaluating the results of the educational activities of universities by the central educational management bodies does not contribute to the introduction of new principles and mechanisms for achieving and constantly improving the quality of scientific and educational activities. This system only registers certain, not always reliable, indicators without taking into account the possible reasons for their formation.

The quality management system of higher education institutions should be based on the created values for educational institutions. This model makes it possible to synthesize and determine the optimal structure and powers of higher education units in a single integrated system to achieve the necessary indicators of the quality of educational work. The essence of the project management methodology is the correct coordination of executors, equipment, materials, funds and works for the successful implementation of a specific project within the given time, budget and to the satisfaction of the customer's (consumer's) conditions [80 - 101].

The evaluation of the competitiveness of research work of universities is a standard component of the management of educational and research institutions. The functioning of universities is often considered as a set of projects, each of

which represents a vector in the space of scientific, educational and administrative activities. Evaluation of the results of these types of activities determines the coordinates of the corresponding vectors. Other approaches offer parametric models for determining the quality of university work, which involves tracking changes in various types of activities and predicting their subsequent results. Others use a Markov chain to predict transitions between states of a university defined by states.

Despite the difficulties and failures that often arise in educational projects implemented by domestic managers and specialists, the transition to professional project management is important. The community of educational projects and their executors in the Ukrainian education system are faced with the increasing complexity of tasks, which requires the development of specific approaches and project management tools. These approaches should reflect the peculiarities of the educational sphere, in particular:

- informational and product nature of most educational projects;
- close integration of project and functional management, the existence of operational and procedural projects;
- use of specific (non-network) methods of planning the educational process;
- vagueness in the organization of execution of work complexes;
- difficulty in determining the persons responsible for the performance of works;
- significant dependence on the decisions of the Ministry of Education, etc.

The use of project management methodology in the field of education is an urgent task that will allow to create a dynamic system and make the education management of Ukraine more flexible, coordinated, purposeful and high-quality [81]. In modern literature, a significant amount of research is devoted to the implementation of project management methodology in the educational sphere, defining it as a necessary direction. This methodology can help in solving the issue of university management and increasing the competitiveness of the university in the conditions of digital transformation. Accordingly, the relevance of developing

methods and models for evaluating the competitiveness of universities is confirmed.

For the effective functioning of educational institutions in modern conditions, it is critically important to improve their management system. This improvement involves the use of modern management methods in all aspects of their activities, including scientific, educational and organizational. For the most part, scientists agree that the higher education system should be independent and self-regulating. The independence of the higher education system involves the minimization of the centralized administrative influence of the state on universities and the development of competitive principles in the field of higher education, including the transition to selective priority funding depending on the rating.

Existing methods of assessing the productivity of subjects of scientific activity have their shortcomings. For example, the convolution method requires the correct selection of weighting factors, which can be difficult to achieve due to subjectivity in each subject's understanding of directions with important results. The ideal point method requires constant refinement of this point and expert evaluation, which also introduces a subjective element into the comprehensive evaluation.

The development of a new comprehensive method of evaluating the productivity of subjects of scientific activity, which can become an effective tool for the management of higher education institutions and their structural divisions, such as departments, faculties and institutes, is urgent. This method should be easily automated for use in higher education management systems.

Another drawback of existing methods is the need for constant intervention in the process of calculating the subjective factor, coordination of experts' opinions, and changes in the system of coefficients when evaluation priorities change. The developed method of evaluating the productivity of subjects of scientific activity has the advantage of easy automation, the absence of the need to involve experts, and the absence of the need to select weighting factors or an ideal point during the construction of a comprehensive assessment. In figure 1.1. and 1.2. the main

indicators of university evaluation according to the QS ratings and the Shanghai rating are described.

Webometrics claims that citation analysis for quality assessment allows for a broader coverage of higher education institutions than citation analysis or expert surveys. This ranking encourages academics and institutions of higher education to increase and improve their online presence. This contributes to the dissemination of knowledge and provides a more objective assessment of the results of activities through their public discussion. The Webometrics methodology uses a predefined model to derive an overall metric. This approach takes into account the power distribution law of data. All indicators are divided into two groups: activity/presence and visibility/impact. Each of these groups has an equal value and as a result gives half of the overall rating of the institution of higher education.

Table 1.1.

Indicators of evaluation of universities according to the QS rating

<b>Activity</b>	<b>Indexes</b>	<b>Relative weight, %</b>
Academic community	<ul style="list-style-type: none"> <li>– academic reputation</li> <li>– H index</li> <li>– faculty citation</li> <li>– scientific and pedagogical staff with scientific degrees</li> </ul>	40
Employers	<ul style="list-style-type: none"> <li>– reputation of the employer</li> <li>– presence of employers in the student campus</li> <li>– employment rate of graduates</li> <li>– results of graduates</li> </ul>	20
Teaching	<ul style="list-style-type: none"> <li>– the number of scientific and pedagogical workers relative to the number of students</li> <li>– student exchange</li> </ul>	30
International activity	<ul style="list-style-type: none"> <li>– share of teachers from other countries</li> </ul>	10

Table 1.2.

Indicators of evaluation of universities according to the Shanghai rating

<b>Activity</b>	<b>Indexes</b>	<b>Relative weight, %</b>
Quality of education	– graduates of the institution who received Nobel and Fields prizes	10
Faculty quality	– graduates of the institution who received Nobel and Fields prizes	20
	– citation of publications by faculty members	20
Research results	– Scientific publications published in Nature and scientific publications indexed in Science Citation Index-Expanded and Social Science Citation Index	20
		20
Efficiency	– Learning outcomes per student unit	10

Common to the methodologies discussed above is the determination of university competitiveness results based on several groups of indicators. In particular, each of the considered ratings takes into account such groups of indicators as:

- the number of scientific publications of employees of higher education institutions indexed in scientometric databases (Scopus, Nature, Science, etc.);
- citation indicators (SCIE – Science Citation Index – Expanded, SSCI – Social Science Citation Index, etc.);
- high-quality staff of higher education institutions, in particular the number of professors, award winners, foreign teachers and scientists involved.

To determine the number of scientific publications of university employees, you can use the following methods:

1. Bibliographic databases. Use scientometric databases such as Scopus, Web of Science, or Google Scholar to search for publications by specific author or university. Many universities also provide access to their library systems for searching the research papers of their employees.

2. Institutional repositories. Many universities have their own institutional repositories where the scientific publications of their staff are stored and searchable.

3. Specialized services. Use online services that specialize in analyzing the indexing of authors and their publications. For example, ORCID can provide unique identifiers for authors and help track their publications.

4. University information systems. Contact the information systems of your university or its department of science and research for statistics on the number of scientific publications of employees.

5. Expert assessments. Contact the academic or research departments of the university for peer reviews or reports on the scientific activities of employees.

6. Altmetry. Use altmetric services that take into account the social influence of posts, such as Altmetric or PlumX.

Citation rates include various metrics that determine how often the articles of a given author, journal, or scientific paper are cited by other researchers. Major databases such as SCIE (Science Citation Index Expanded), SSCI (Social Science Citation Index) and others determine the citations of scientific publications. Below we consider some key indicators of citation:

1. Impact Factor (IF). IF is a metric calculated for scientific journals. It represents the average number of citations per article published in the journal during a certain period. It is defined as the ratio of the number of journal citations to the number of articles published in this journal.

2. Hirsch Index (h-index). h-index is defined as the number at which an author has h articles, each of which has at least h citations. This indicator evaluates the quality and number of cited publications of the researcher.

3. Citation Count (Number of citations). A simple sum of all citations received by an author or article can serve as an indicator of total citations.

4. Eigenfactor Score. This metric measures the importance of a journal based on the number of citations that come from other important journals. It is used to evaluate the influence of journals in the scientific community.

5. Field-Weighted Citation Impact (FWCI). FWCI calculates the weighted impact of citations for a particular discipline or science.

Determining the quality of employees of higher education institutions may include a number of indicators that indicate a high level of professional qualification and active scientific and educational activity. Among these indicators, the main role is played by the number and rank of professors. An important indicator of the quality of staff is the number of professors in a higher education institution. The professorial corps, especially those with high academic degrees, testifies to a high level of scientific and pedagogical expertise. Also an important indicator is the number of prize winners and outstanding achievements of employees. The number and level of awards, such as national and international prizes, can serve as indicators of high academic expertise and significant contributions to science and education. Another indicator is the involvement of foreign teachers and scientists. Attracting highly qualified foreign specialists may indicate international recognition and the desire to develop international academic ties.

Participation in scientific projects and work on scientific publications are also taken into account to determine the quality of university employees. Active participation in scientific research and a high level of publications are also important indicators of academic productivity and quality. Also, an important indicator is the success of students and graduates, their participation in competitions, awards, success in the labor market, which can indicate the quality of the education provided.

The obtained results of the analysis are important for evaluating the

competitiveness of universities.

## **Conclusions to chapter 1**

1. The chapter describes the features of using system-dynamic modeling of the educational activity of universities, identifies the key aspects that affect the positive dynamics of the university's development from the point of view of system dynamics. It is indicated that the use and improvement of the project management methodology applied to the educational activities of universities is a guarantee of their progressive development and increased competitiveness, especially in the conditions of digital transformation, which the education system is currently experiencing.
2. It is shown that evaluating the competitiveness of universities is a complex and multidimensional process, which includes the analysis of various aspects of the activity of educational institutions. The main methods and criteria for evaluating the competitiveness of universities are indicated, which include the calculation of academic indicators, indicators of the quality of the educational process, research activities of the university and international activities, evaluation of the university infrastructure and resources, as well as the effectiveness of management and reporting in general. A review of these indicators is necessary for further calculations and the construction of methods for evaluating the competitiveness of universities.
3. An analysis of modern provisions in the management of educational projects of the university was carried out. It was revealed that the existing practice of determining the quality of educational activities of educational institutions, as a rule, is focused on evaluating the success of students in learning knowledge. However, for a full-fledged and comprehensive assessment of the competitiveness of universities, all components that affect this activity are important. The need for a comprehensive study of

them is especially evident in the conditions of digital transformation. Accordingly, the relevance of developing methods and models for evaluating the competitiveness of universities is confirmed.

## **CHAPTER 2. THE CONCEPT OF ASSESSING THE COMPETITIVENESS OF UNIVERSITIES AS PART OF THEIR EDUCATIONAL ACTIVITIES IN DYNAMICS**

### **2.1. A multiple model of presenting data on the educational activity of universities and a method of calculating their competitiveness**

The conducted analysis confirmed that the current method of implementation of projects in the educational sector already at the initial stage does not fully meet the current requirements. The evaluation of the competitiveness of universities in such a context is also complicated. According to the traditional model of project management, their essence is considered as an internal element of the management system, which does not stand out from the general context of analysis, planning and implementation, but is a component embedded in this general scheme (see Fig. 2.1).

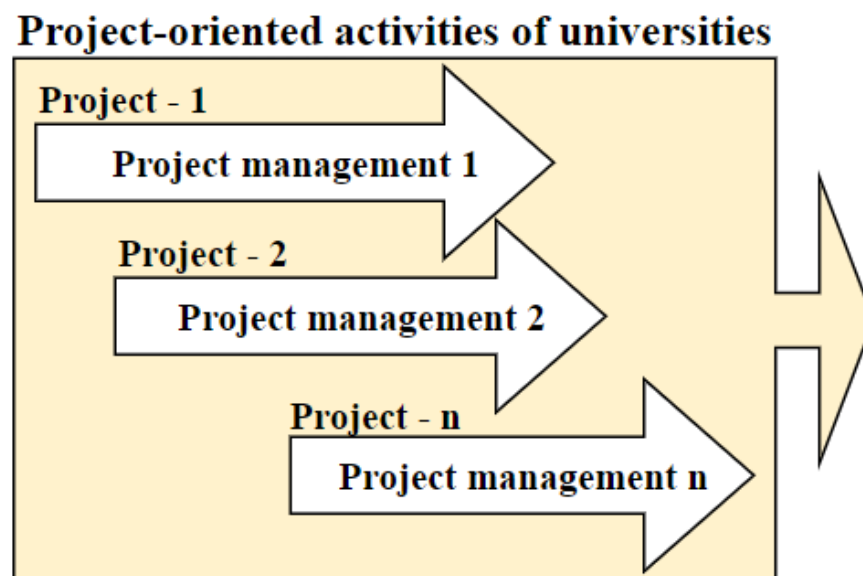


Figure 2.1. – Project-oriented project implementation scheme in universities.

The traditional model of project implementation in universities leads to the fragmentation of managerial activities, an increase in the volume of interactions between project participants and the presence of different concepts, approaches,

principles, methods and management regulations, which leads to high costs and time spent on the implementation of individual projects and the inefficiency of their management. Standardization of approaches and minimization of costs for managing individual projects is possible if a single system of organization, methodology and technology is implemented, particularly in the field of university education. The need to create a project management system is due to the following arguments:

1. With a limited number and simplicity of projects, they can be managed independently of each other. However, if the number of projects is doubled, the cost of managing them will not double, but many times over.

2. When the complexity of project implementation doubles, management costs increase not by two, but by three to five times or even more. The regularity of the increase in costs is due to the fact that with an increase in the number or complexity of projects, the number of interactions in their management grows exponentially.

3. To avoid an endless increase in management costs when the number or complexity of project implementation increases, it is necessary to streamline all interactions in the process of managing them.

It is necessary to define a standard part of management functions, which will be the same for all projects, and to centralize it. The remaining functions should be clearly regulated to eliminate impacts on project management, i.e. create a project management system. This is important in the conditions of digital transformation of education. A qualitatively built system will allow you to effectively and quickly determine the competitiveness of the university and respond accordingly to possible shortcomings in educational activities.

To implement such a system, it is necessary to determine the general and characteristic features of projects and, taking into account their specifics, to develop the scientific and methodological foundations of project management in the educational sphere. In modern information systems, great importance is attached to a special type of information resources, which are known as metadata.

This includes bibliographic descriptions of used sources in scientific publications, various classifiers and article annotations - all these elements refer to the metadata of scientometric subjects, which have the task of assigning a unique identification to scientometric subjects.

Despite the fact that metadata is currently receiving considerable attention, the interpretation of the term "metadata" remains unstable. Depending on the field of application and purpose of metadata, the term requires certain adjustments and modifications that change their properties and functions.

Consider the history of attention to metadata management. In the 1970s, in the context of information systems working with structured data, metadata management began to receive serious attention. The concept of a data dictionary system has been proposed, and a number of similar systems have been developed. A little later, the concept of integrated data reference dictionaries appeared - database management systems that perform the traditional functions of databases and at the same time the functions of a data dictionary-reference system.

During the last two decades, metadata has become the object of many studies, especially in the context of the development of semantic-web technology, electronic libraries and other information technologies. This has led to an active standardization of metadata, with international standardization bodies, industry consortia, scientific and other organizations playing a leading role.

In advance, it is important to clearly define the term "metadata". Metadata of scientometric subjects are structured data that are characteristics of the described entities. The main purpose is to classify, search, evaluate and manage them. The task of scientometric metadata is to define the terminology of scientometric identifiers, classify information objects in the relevant system and formalize the laws of their creation and use.

It is rightly argued that data in a particular information system reflect abstract or material entities such as objects, processes, and phenomena. In this case, it is appropriate to talk about information objects - blocks of information that represent the relevant entities in the information system. Metadata describing these

objects or their group is an effective means of managing information processes on a given set of information objects. In figure 2.2. the scheme of connections in the information system for assessing competitiveness is indicated. According to this scheme, it can be seen that for the stable operation of the competitiveness assessment system, it is necessary to collect a sufficient amount of information about the educational activities of universities.

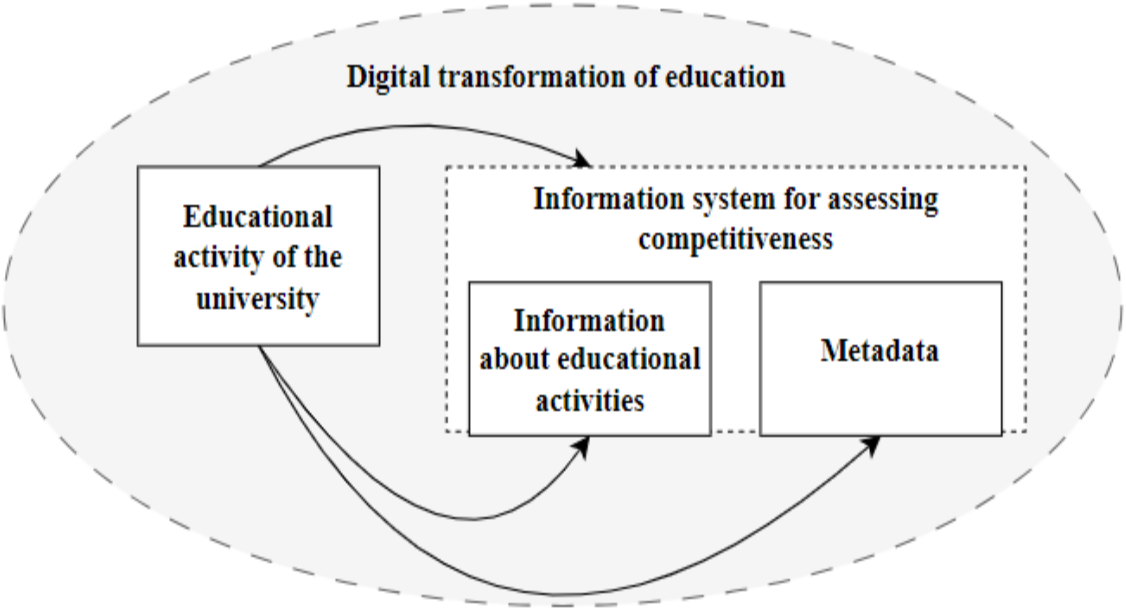


Figure 2.2. – Scheme of connections in the information system for assessing competitiveness

The scheme of metadata for the description of the model of educational activity of universities is shown in Table 2.1.

Let's assume that the evaluation of the educational activity of the university is a numerical indicator that reflects the general level of compliance with the requirements and criteria established by the Ministry of Education and Science of the country. It is assumed that each university must meet the requirements imposed on it, performing the specified tasks within the specified time and at the appropriate level of quality.

Table 2.1.

Metadata scheme for describing the information model  
educational activities of universities

<b>Name</b>	<b>Description</b>	<b>Elements and data types</b>
Scientific publication	Information object of the first level	subject = {string} Abstract = {text} keywords = {string} Bibliographic data = {link} DOI = { numeric code }
University	Institution of higher education	Name = {string} Specialty = {classifier} keywords = {string}
Event	Conference, workshop, etc	Name = {string} description = {text} keywords = {string} Service = {lunch, buffet, hotel}
Author	Determines the author(s) of the scientific publication	first_name = {string} ORCID = { numeric code } Institution = {list of institutions}
Project	Limited in time, resources and quality requirements, a unique set of processes aimed at creating new value	Patent = {document} Reward = {type, amount of reward} Funding = {institution, state} Equipment = {computer, projector}

To evaluate the educational activity of the university, it is assumed that the university is the highest link in the hierarchy of scientometric subjects. So, it

becomes obvious that in order to evaluate the educational activity of the university, it is necessary to have calculation data for entities of a lower level. Among these entities, you can specify articles published by the institution, journals (if the institution is their publisher), as well as the authors of the relevant publications.

The main purpose of placing scientific works on the Internet is to create a global database of scientists, scientific publications, scientific journals and universities to determine the citation rating and competitiveness of the specified subjects. The publication activity of scientific and pedagogical staff of the university and the university's ability to publish scientific journals of a correspondingly high category are equal to the potentially high competitiveness of the university. Accordingly, publication activity is one of the parameters of competitiveness. Educational activity includes publishing activity, since component education cannot be considered separately from scientific, especially for the activities of universities.

Consider the multiple model of presentation of scientific publications as a system with an ordered set of the following elements and present it in the form of a tuple:

$$N = \langle A, B, C, D, f_{A,B} \rangle, \quad (2.1)$$

where  $A = \{a^1, a^2, \dots, a^{n_a}\}$  – multiple system users,  $a^r$ ,  $r = \overline{1, n_a}$  – r system user,  $n_a$  – the number of system users;

$B = \{b^1, b^2, \dots, b^{n_b}\}$  – set of scientific and journalistic objects of the system,  $b^i$ ,  $i = \overline{1, n_b}$  – scientific publication,  $n_b$  – number of scientific publications;

$C = \{c^1, c^2, \dots, c^{n_c}\}$  – set of system user applications,  $n_c$  – number of applications;

$D = \{d^1, d^2, \dots, d^{n_d}\}$  – many messages to system users,  $n_d$  – the number of messages;

$f_{A,B}$  – function to determine the score of posts, which takes into account the number of external links received by posts  $B$  from users  $a$ ,  $a \in A$ , as well as the "weight" of the user who is the author and refers to the corresponding publication. When evaluating the activity of scientometric entities, we do not take into account the quality of scientific publications. The set of scientific and journalistic objects  $B$  of system  $A$  is determined by scientific publications available in this system, each of which is determined by a set of attributes and metadata:

$$b_i = \{e, f, m, D\}, \quad (2.2)$$

where  $b_i \in B$  – scientific publication;

$e$  – volume of scientific publication (number of words, number of characters, file size including format, images, etc.);  $f$  – формат публікації (\*.doc, \*.rtf, \*.pdf і т.д.);

$m$  – additional materials for publications (drawings, formulas, graphs, schemes, diagrams, etc.);

$M$  – a set of scientific publication metadata.

Application  $C$  will be considered a request from the user to publish a scientific article  $b_i$  and define it as a tuple:

$$C_i^r = \langle a^r, b_i \rangle, \quad C \subset A \times B, \quad (2.3)$$

where  $a^r$  – the user who created the request;

$b_i$  – scientific article submitted by the user for consideration.

We will consider a message  $M$  to be a set of recommendations for correcting/editing or approving the sent publication, which are defined by a tuple:

$$M_{ik}^r = \langle C_i^r, T_k \rangle, \quad (2.4)$$

where  $C_i^r$  – request from the user;

$T = \{T_1, T_2, \dots, T_k\}$  – a set of messages and/or recommendations for correction or approval of a scientific publication,  $k = \overline{1, n_T}$ ,  $n_T$  – number of responses. Thus, we assume that some magazine  $J$  consists of  $n$  scientific and journalistic objects  $O_y$ ,  $y = \overline{1, n}$ :

$$J = \{O_1, O_2, \dots, O_n\}, O_y \subseteq B. \quad (2.5)$$

For multiple releases  $O_y$ , relating to the respective journals  $J$  of some university by some composition  $\gamma_o$  can be compared  $m_o$  images (scientific publications), each of which is a scientific and journalistic object  $s_i$ , then we get:

$$\begin{aligned} \gamma_o: J &\rightarrow B, \\ \gamma_o(O_y) &= \{B_1^{O_y}, B_2^{O_y}, \dots, B_{m_o}^{O_y}\}, \end{aligned} \quad (2.6)$$

where  $B_{m_o}^{O_y}$  – a number of scientific publications in the issue  $O_y$ .

In addition, it is necessary to ensure the fulfillment of the conditions for the correct format of presentation of publications:

$$\left. \begin{aligned} e_{b_i} &\leq e_{\max}, e_{b_i} \in b_i^{O_y} \\ p_{i \min} &\leq p_i \leq p_{i \max}, p_i \in M \subset b_i^{O_y} \end{aligned} \right\}, \forall b_i \in O_y \quad (2.7)$$

where  $e_{b_i}$  – publication volume,  $b_i^{O_y}$  – number of words, number of characters, file size including format, images, etc.;

$e_{\max}$  – maximum allowed volume of publication  $s_i^{O_y}$ ;

$p_i$  – article metadata attribute  $M$ , which reflects the number of internal links in the publication  $b_i^{O_y}$ ;

$p_{i \min}$  – the minimum number of references allowed in a publication  $b_i^{O_y}$ ;

$p_{i \max}$  – maximum number of references allowed in the publication  $b_i^{O_y}$ .

Function  $f_{A,B}$  is based on calculating the product of the ratio of the total volume ("weight") of a particular citation to the total volume of the text of a scientific publication and the "weight" of the author who refers to the relevant

publication. The criteria for assessing the quality and results of scientific activity are the aggregated set of scientometric entities themselves E:

$$E = \langle B, J, I \rangle, \quad (2.8)$$

where E – tuple of scientometric subjects;

B – a set of items to be evaluated;

J – a set of journals to be evaluated;

I – a set of universities to be evaluated.

Let's consider the set of components of DB scientific content as a combination of data sets, metadata, and documents:

$$DB = \bigcup_{i=1}^{n_E} M(Y_i), \quad (2.9)$$

where  $n_E$  – the number of levels of the hierarchy of scientometric entities to be evaluated (in this case, there are three: articles, journals, and institutions);

$M(Y_i)$  – a set of data and metadata of scientometric entities that correspond to the current level of the  $Y_i$  hierarchy (article, journal, institution):

$$f_{A,B}: E \rightarrow \bigcup_{i=1}^{n_E} Y_i$$

$$Y_i = \{B \vee J \vee I\}. \quad (2.10)$$

Based on the formulas for calculating (2.9), (2.10), the mathematical model of the system, which is the basis for assessing the competitiveness of scientometrics subjects or universities, is as follows:

$$DB = \left\langle \bigcup_{i=1}^{n_B} M^B(Y_i), \bigcup_{i=1}^{n_J} M^J(Y_i), \bigcup_{i=1}^{n_I} M^I(Y_i) \right\rangle, \quad (2.11)$$

where  $M^B(Y_i)$  – a set of data and metadata of scientometric entities that reflect the level of the "publication" hierarchy B,  $n_B$  – total number of publications in the system.

$M^J(Y_i)$  – a set of data and metadata of scientometric entities that reflect the "journal" hierarchy level J,  $n_J$  – the total number of journals in the system.

$M^S(Y_i)$  – a set of data and metadata of scientometric entities that reflect the "institution" hierarchy level  $I$ ,  $n_I$  – the total number of institutions in the system.

It is clear that we are talking about a dynamic system, i.e. a system that changes over time. The variable in this system is the number of scientific publications (if we are talking about one journal of one university or organization), so we modify the model as follows:

$$DB = \left\langle \bigcup_{t=t_0}^{t_1} \left( \bigcup_{i=1}^{n_B} M^B(Y_i) \right), \left( \bigcup_{i=1}^{n_J} M^J(Y_i) \right), \left( \bigcup_{i=1}^{n_I} M^I(Y_i) \right) \right\rangle, \quad (2.12)$$

where  $t_0$  – the time when the first link to the publication was made in the system;

$t_1$  – current moment in time;

$t \in [t_0; t_1]$  – a period of time within which the university's competitiveness is assessed for  $J = \text{const}$ ,  $I = \text{const}$ .

Let us consider time to be discrete with a certain period  $\Delta t = \{\text{day, week, month, quarter, year, ...}\}$ :

$$t = t_0 + \kappa \Delta t, 0 \leq \kappa \leq \frac{t_1 - t_0}{\Delta t}. \quad (2.13)$$

$$\pi: B \rightarrow R,$$

$$Z(DB) = \{\pi(b_i) \mid \overline{i=1, n}, \sigma(b_i) = 1\}, \quad (2.14)$$

where  $Z(DB)$  – request for evaluation of scientific publications;

$\sigma(b_i)$  – selection condition, which is equal to 1 if condition (2.7) is met or equal to 0 if condition (2.7) is not met;  $b_i$  – the scientific publication to which the request was made.

The purpose of the developed method includes, first of all, the development of a concept and tools for assessing the competitiveness of the educational activities of the university and its structural units, and secondly, the implementation of the proposed models and methods in a specific information

system for managing scientometric content. With the help of the developed method, it will be possible to compare the competitiveness ratings of universities, to evaluate the effectiveness of universities according to various criteria in different periods and moments of time. This will allow for an effective and objective assessment of university competitiveness.

However, the development of a method for assessing the competitiveness of a university's educational activities is complicated by the lack of comparability of universities by a number of parameters. Therefore, at this stage, there is a need to create appropriate metrics that will allow grouping universities by different characteristics and determining the appropriate normalizing coefficient or function for each group.

Considering the educational activity of the university as a numerical indicator of the level of compliance with the requirements of the Ministry of Education and Science, it is necessary to compile data on the university's compliance with the relevant requirements and criteria, as well as to perform a mathematical transformation to bring all data to values in the interval [0; 1].

Consider a set of criteria for assessing the competitiveness of a university

$$\mathbf{K} = \{k_1, k_2, \dots, k_W\}, \quad (2.15)$$

where  $W$  – number of criteria.

Let's represent the satisfaction of a set of criteria for a certain university at a certain point in time  $T$  in the form of a segment with zones of qualitative compliance with these criteria: "unsatisfactorily", "satisfactorily", "fine", "perfectly" (Fig. 2.3).

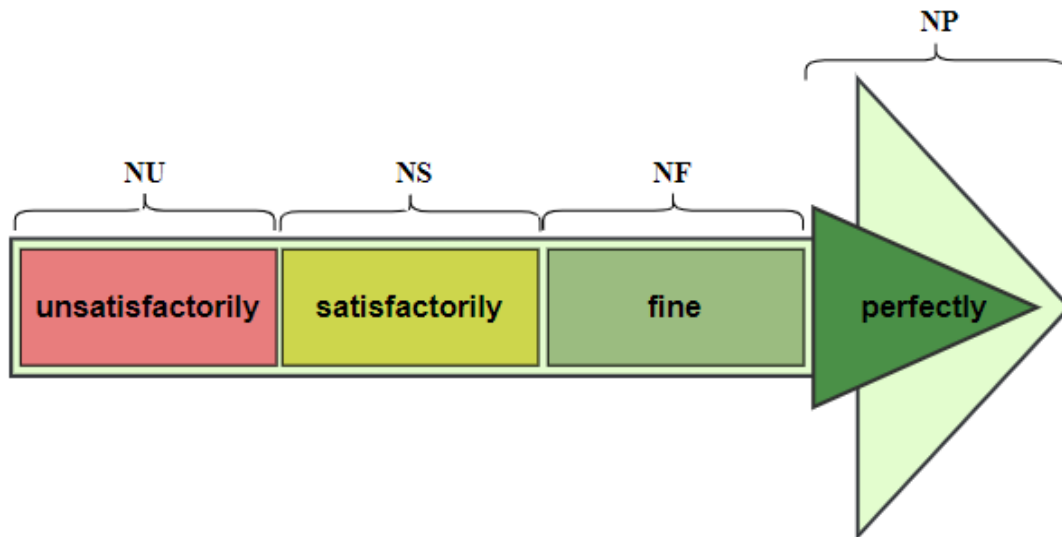


Figure 2.3 - Representation of the university's educational activity at some point (period) of time T to assess its competitiveness

W – the total number of criteria and requirements that the university must meet;

NP – the number of criteria that correspond to the "perfectly" zone;

NF – the number of criteria that correspond to the "fine" zone;

NS – the number of criteria that correspond to the "satisfactorily" zone;

NU – the number of criteria whose satisfaction corresponds to the "unsatisfactorily" zone.

Then

$$W = NP + NF + NS + NU. \quad (2.16)$$

Let's establish the following interpretation:

- perfect: it is considered that the fulfillment of the criterion fully meets the requirements of the ministry and the university fulfills it at a very high level or exemplary;

- fine: in general, the value of the indicator is acceptable, but for some reasons it cannot be considered exemplary, i.e. the level of satisfaction of the criterion corresponds to the average level compared to other universities;

- satisfactorily: the value of the indicator generally meets the criterion, but it can be assumed that the indicator is generally below the average level compared to other universities;

- unsatisfactorily: the value of the indicator does not meet the criterion;

Thus, the assessment of the educational activity of the  $i$ -th university at time  $t$  is defined as four indicators that determine the number of criteria that satisfy the four categories ("unsatisfactorily", "satisfactorily", "fine", "perfectly"):

$$G_i^t = (NU_i^t, NF_i^t, NS_i^t, NP_i^t). \quad (2.17)$$

The parameters are calculated with a frequency of one quarter.

The easiest way to determine the competitiveness of the  $i$ -th university is to determine its competitiveness:

$$\bar{G}_i^t = \frac{1}{W} (NU_i^t + NF_i^t), \quad (2.18)$$

where  $\bar{G}_i^t$  - assessment of the competitiveness of the  $i$ -th university at a given time  $t$ ,  $\bar{G}_i^t \in [0,1]$ .

Since there are always the same number of criteria for the calculation, this assessment can be used to compare universities with each other.

To evaluate the educational activities of a university, it is necessary to determine a list of criteria and requirements for the university, and then to classify it according to the satisfaction of the criteria (Table 2.2).

The results obtained will vary from 0 to 1. A value of 0 means that the university has low competitiveness, a value of 0.5 indicates an average level of competitiveness, and a value of 1 means high competitiveness. This can be used to assess the university's participation in international projects and the accreditation of the university by the ministry, which is periodically conducted to confirm the level and quality of knowledge provision.

Table 2.2

Classification of criteria and requirements for a university to assess its competitiveness

№	Criteria (requirements)	Incoming info.	Source info.	Rule	Satisfying requirements			
					Unsatisfactorily	Satisfactorily	Fine	Perfectly
1	Profes. staff	DB teachers	Number of professors	Query to the database	–	–	+	–
2	Number of state prize winners	DB teachers	Number of winners	Query to the database	–	+	–	–
...	...				...			
n	Participation in projects	List of projects	Number of projects	List of projects	+	–	–	–

## 2.2. The concept of dynamic assessment of the competitiveness of educational activities of universities

Since university indicators are constantly changing, the following calculation formula can be used to dynamically take into account the potential or competitiveness of a university. The competitiveness score of the  $i$ -th university will be defined as the ratio of the number of criteria that received a positive score to the number of criteria that received a negative score  $p$  periods ago, i.e:

$$\overline{\overline{G}}_i^t(p) = \frac{NU_i^t + NF_i^t}{NU_i^{t-p} + NF_i^{t-p}}, \quad (2.19)$$

where  $\overline{\overline{G}}_i^t(p)$  - is an assessment of the competitiveness of the  $i$ -th university at time  $t$ , if the comparison period is  $p$ ,  $\overline{\overline{G}}_i^t(p) \in [0,1]$ .

Then, having calculated these indicators for a certain list of universities, we will get a time series of performance indicators for each university:

$$G_i(p) = \left( \overline{\overline{G}}_i^1(p), \overline{\overline{G}}_i^2(p), \dots, \overline{\overline{G}}_i^n(p) \right). \quad (2.20)$$

The value of the criteria can change, so a good assessment of the university's educational activities can be a positive increase in the level of the specified series compared to the level recorded  $q$  periods ago:

$$\Delta_i^{p,p-q} = \overline{\overline{G}}_i^p(p) - \overline{\overline{G}}_i^{p-q}(p), \quad (2.21)$$

if the sign of the increase is positive, then the university's competitiveness is increasing.

Since the value and satisfaction of the criteria is determined according to the requirements of the Ministry, and the evaluation takes place in the context of comparing the scores of other universities. In particular, to take into account the exemplary level of criterion satisfaction, it is necessary to understand that the university is exemplary in comparison with others, i.e. other universities do not have such results or such exclusive practices or have not yet implemented them. Accordingly, to assess the competitiveness of a university, there is no need to explicitly compare the assessment of satisfaction of certain criteria for other universities.

However, if the competitiveness score for the  $i$ -th university exceeds the score for the  $j$ -th university, i.e.  $\overline{\overline{G}}_i^t(p) > \overline{\overline{G}}_j^t(p)$ , then university  $i$  is more competitive.

Let  $\overline{\overline{G}}_i^t(p) > \overline{\overline{G}}_j^t(p)$ , i.e., university i is superior to university j in terms of competitiveness. We can introduce the following scale to compare the competitiveness of universities among themselves (Table 2.3)

Table 2.3.

Scale of comparison of universities by the level of competitiveness

№	$\overline{\overline{G}}_i^t(p) - \overline{\overline{G}}_j^t(p)$	Interpretation of comparison results
1.	[0,75;1]	High level of competitiveness
2.	[0,50;0,75)	Sufficient level of competitiveness
3.	[0,25;0,50)	Average level of competitiveness
4.	[0;0,25)	Low level of competitiveness

Having received the assessment of the educational activities of each university or structural unit, it is possible to conduct a comparative analysis of the competitiveness of these institutions. It is worth noting that the application of the proposed approach allows for effective correction of shortcomings through the optimal allocation of resources.

Since all universities, structural subdivisions and research organizations have a similar composition and structure, the first task is to categorize universities into groups with approximately the same values of indicators. To do this, we can use similarity coefficients between the quantitative parameters of similar indicators in each category of universities. For example, to compare the indicator of the number of publications of authors for a certain period with the indicator of the total number of publications. Similar comparisons are made within each category of universities.

Further, quantitative characteristics with similar parameters are compared with other categories of universities. Universities can be categorized based on the maximum values of similar indicators within the established limits for each category. This approach allows comparing the quality of universities and their research and educational activities.

The next step is to define linguistic variables to reflect the qualitative state of the relevant indicators. For example, for the variable "research and publishing activity", values such as "excellent", "good", "mediocre", "satisfactory" and "unacceptable" can be defined. Each value of the variable is assigned a corresponding numerical equivalent, which is justified and standardized, possibly using fuzzy logic methods, which provides flexibility in setting the parameters.

The created method allows comparing university rankings, evaluating efficiency according to various criteria, and tracking the dynamics of university and research structures. The results of the study can serve as an incentive to create new technological developments and present them in scientific publications, which, in turn, will become part of the assessment of the quality of scientific activities of universities using this method. The study aims to resolve contradictions in the assessments of scientometric entities related to the diversity of university categories, types of scientific publications, journal categories, etc., which complicates the comparison and objective assessment of existing and new scientific publications, and therefore all other scientometric entities.

### **2.3. Parameters that determine the competitiveness of universities and data coverage analysis**

Let  $A = \{a_1, \dots, a_n\}$  are higher education institutions, the competitiveness of which needs to be monitored. Each institution of higher education has been fully functioning for at least ten years. Accordingly, information on various aspects of activity, educational, scientific, financial, international, etc., has been preserved about the activities of such a higher education institution. Each pair of institutions of higher education  $(a_i, a_j)$ ,  $i \neq j$ ,  $i = \overline{1, n}$ ,  $j = \overline{1, n}$  are competitors. Institutions of higher education compete if they offer similar programs of study and have similar academic resources. In addition to higher education institutions, competitors can be technical schools, training centers, and centers for advanced training, especially in information technology. Competition between higher education institutions can improve the

quality of education and increase student choice. Still, it also challenges each institution of higher education to create an attractive learning experience and provide high-quality education and services for its students.

The task is to monitor the competitiveness of each institution of higher education  $a_i$ ,  $i = \overline{1, n}$ , which takes into account the activities of competitors and is based on the analysis of open performance indicators that do not depend on the main direction of the universities.

Monitoring is a process of systematic observation, control, and data collection about particular objects, phenomena, or processes. The primary purpose of monitoring is to obtain up-to-date information about the state of the object or phenomenon to make informed decisions, detect anomalies in time, respond to them, and improve the control process.

The competitiveness of a higher education institution is the ability of a higher education institution to compete effectively in the market of educational services and gain a particular market share or increase its position relative to other players in this field, that is, other higher education institutions. Competitiveness is an essential factor for the successful operation of a higher education institution. The competitiveness of a higher education institution is essential for attracting students, ensuring their high-quality education, and preparing them for a successful career.

To organize monitoring of the competitiveness of a higher education institution, it is necessary to collect data on various types of activity of a higher education institution during a specific period and save them for processing. Data should be open, verifiable, transparent, and easy to verify. They should be free from the influence of the subjective factor. This is important to ensure an unbiased assessment of the activities.

The model for monitoring a higher education institution's competitiveness includes several steps and components that help analyze and evaluate the institution's effectiveness in competitive conditions. Here is the general model for monitoring the competitiveness of HEIs:

1. Determination of key performance indicators. These indicators include academic quality, reputation, foreign partnerships, number and quality of students, financial sustainability, etc.

2. Data collection. After collecting a list of key indicators, develop a data collection system for these indicators. This may include analysis of existing data, student surveys, alum surveys, financial statements, etc.

3. Data analysis and evaluation. After the data has been collected, it is necessary to conduct an analysis and evaluation to find out how the institution of higher education compares to its competitors. Determination of strengths and weaknesses of a universities.

4. Setting goals and strategies. Based on the analysis results, setting goals and developing strategies to improve competitiveness is necessary. These goals and strategies should be specific, measurable.

5. Implementation of measures. Implementation of strategies aimed at improving competitiveness. This may include modernization of programs, improvement of the quality of education, development of marketing campaigns, improvement of financial stability, etc.

6. Monitoring and evaluation of results. Constantly monitor the impact of strategies on the institution's competitiveness. Use the metrics to determine whether you have achieved your goals and adjust your actions accordingly.

7. Reporting and communication. Reporting to stakeholders such as administration, faculty, students, parents, financial sponsors, etc.

8. Adaptation and improvement. Based on the obtained results, it is necessary to make adjustments in the strategy and activities to maintain or improve the competitiveness of the higher education institution.

Aspects that a higher education institution should take into account to ensure competitiveness:

1. Academic quality. Ensuring high-quality education is the most critical aspect of competitiveness. This includes the quality of educational programs, the qualifications of teachers, research activities, and access to relevant educational

resources and technologies.

2. Accessibility and financial availability. An institution of higher education should be accessible to various groups of students, including those with limited financial means. The availability of scholarships, financial support programs and flexibility in payment options can increase competitiveness.

3. Variety of programs. Providing various study programs and majors helps attract students with diverse interests and career goals.

4. International cooperation. A higher education institution can increase competitiveness by cooperating with other universities and taking educational programs abroad.

5. Infrastructure and technical support. Modernization of the campus, access to modern technologies, library resources and research laboratories help to increase competitiveness.

6. Career support. A higher education institution can provide career counseling services, internships and work with employers to prepare students for the labor market.

7. Involvement of students and the community. Active participation of students in various aspects of university life and cooperation with the community can increase the attractiveness of a higher education institution.

8. Reputation and ratings. A higher education institution can increase its competitiveness by gaining a good reputation and high places in world university rankings.

These aspects can be included in the following parameters:

1. Scientific research and practical development. It includes the research work of the employees of the institution of higher education, the scientific and technical implementation of the results of this work, the presence of scientific schools, etc.

2. Sustainability in the educational services market. It includes the quality of performance of the educational part of the work, the results of recruitment of new students, employment of graduates, etc.

3. Adaptability to changes. Availability of new programs, frequency of

revision of educational programs, availability of elective courses in programs, modernization of study facilities and campus, research laboratories, etc.

4. Participation in alliances, projects, and clusters. Cooperation with other universities, including abroad, within joint projects, inclusion in university clusters in certain areas, etc.

5. The level of competence of scientific and pedagogical staff. Level of knowledge, certifications, indexes of scientific indicators of employees.

6. Assessment of financial status. It includes the university's financial capacity for development and financial accessibility, i.e., providing the opportunity to study for students of different groups, etc.

Thus, if a discrete time is given  $(t_1, t_2, \dots, t_T)$  for assessing competitiveness, a tuple can be formed:

$$O_j(a_i) = \langle S_i^j, Q_i^j, C_i^j, M_i^j, K_i^j, F_i^j \rangle, \quad i = \overline{1, n}, \quad t = \overline{1, T}, \quad (2.22)$$

-  $O_j(a_i)$  is a tuple with evaluations according to six parameters, which is defined for a higher education institution (HEI)  $a_i$  at a time moment  $t_j$ ;

-  $S_i^j$  is an assessment of research work of employees of HEI  $a_i$  at a time moment  $t_j$ ;

-  $Q_i^j$  is an assessment of the flow rate of HEI  $a_i$  at a time moment  $t_j$ ;

-  $C_i^j$  is an assessment of the adaptability to changes of HEI  $a_i$  at a time moment  $t_j$ ;

-  $M_i^j$  is an assessment of HEI  $a_i$  at a time moment  $t_j$  with other universities, including abroad within joint projects, etc.;

-  $K_i^j$  is an assessment of the level of competence of scientific and pedagogical staff of HEI  $a_i$  at a time moment  $t_j$ ;

-  $F_i^j$  is an assessment of the financial stability and financial condition of HEI  $a_i$  at a time moment  $t_j$ ;

One of the methods that can help assess the competitiveness of higher

education institutions is the data coverage analysis (DEA) method. However, the application of this method to this problem has yet to be studied. In addition, the interpretation of DEA results, considering the modifications of the optimization task of assessing the competitiveness of higher education institutions, remains unexplored. Since the analysis of competitiveness consists of comparing the evaluations of different institutions of higher education on different criteria, the DEA method, which is a method of comparative analysis, should be well suited to this task. The main issues of constructing the DEA method are described in works [50, 51].

Let the set be given

$$D = \{D_1, D_2, \dots, D_w\}, \quad (2.23)$$

where  $D_j$ ,  $j = \overline{1, w}$  are decision making units. Each decision making unit uses  $L_1$  inputs  $x_r^j$ ,  $r = \overline{1, L_1}$  and generates  $L_2$  outputs  $y_k^j$ ,  $k = \overline{1, L_2}$ . Output  $y_k^j$  corresponds to price  $U_k^j$ , input  $x_r^j$  corresponds to price  $V_r^j$ , then:

$$\theta^j = \frac{\sum_{k=1}^{L_2} y_k^j U_k^j}{\sum_{r=1}^{L_1} x_r^j V_r^j}, \quad (2.24)$$

where  $\theta^j$  is a ratio of weighted inputs and outputs for each  $D_j$ ,  $j = \overline{1, w}$ .

If the input and output prices are unknown, then a nonlinear programming problem needs to be solved:

$$\theta^j = \frac{\sum_{k=1}^{L_2} y_k^j U_k^j}{\sum_{r=1}^{L_1} x_r^j V_r^j} \rightarrow \max, \quad (2.25)$$

$$\sum_{k=1}^{L_2} y_k^j U_k^j \leq \sum_{r=1}^{L_1} x_r^j V_r^j, \quad j = \overline{1, w}, \quad (2.26)$$

$$U_k^j \geq E, \quad V_r^j \geq E, \quad E \geq 0, \quad r = \overline{1, L_1}, \quad k = \overline{1, L_2}.$$

This problem is reduced to a linear programming problem for a fixed  $j$  based

on the substitution of variables:  $s_k = tU_k$ ,  $b_k = tV_r$ ,  $t = \left( \sum_{r=1}^{L_1} x_r^j V_r^j \right)^{-1}$ . Then:

$$\theta^j = \sum_{k=1}^{L_2} y_k^j s_k \rightarrow \max, \quad (2.27)$$

$$\sum_{r=1}^{L_1} x_r^j b_r = 1, \quad \sum_{k=1}^{L_2} y_k^j s_k \leq \sum_{r=1}^{L_1} x_r^j b_r, \quad j = \overline{1, w},$$

$$s_k \geq E, \quad b_r \geq E, \quad E \geq 0, \quad r = \overline{1, L_1}, \quad k = \overline{1, L_2}.$$

To apply the DEA method, it is necessary to determine the input and output parameters for each of the competitiveness assessments described above. Implementing the model and calculating grades for higher education institutions is also necessary. Estimates of the specified six parameters for ten higher education institutions from the People's Republic of China have been collected. The data is entered into a database that is updated monthly. In this way, a time series of competitiveness assessments are formed. These estimates will be used to build a monitoring system.

## Conclusions to chapter 2

1. It is determined that the educational activity of a university is a complex of both the educational component (quality of teaching and teaching materials, etc.) and the research component (publication activity, project and research activity). The section describes a multiple model for presenting data on the educational activities of universities in terms of the publication activity of research and teaching staff. A data presentation scheme has been formed: university, university employee, university events, etc. The described model takes into account and formalizes aspects of the university's educational activities, which is the basis for calculating competitiveness assessments and is characterized by a systematic approach to building dependencies and relationships necessary for calculating the parameters.

2. The method of calculating the competitiveness of the university, which is calculated by the number of criteria that the university meets, is built. The criteria are formed in accordance with the requirements of the Ministry and are intended for accreditation of the university as an educational structure as a whole, but the list and value of the criteria can be set by the organization that evaluates the educational activities of the university.
3. The formulas for calculating the competitiveness of the university in the dynamics, defined as the ratio of the number of criteria that received a positive assessment to the number of criteria that received a negative assessment  $p$  periods ago, have been established. The scale of comparison of universities by the level of competitiveness is built and described. The system of parameters that determine the competitiveness of universities is built and the method of data coverage analysis is described, which can be used for a preliminary assessment of the competitiveness of the university and is based on the built parameters.

## **CHAPTER 3. METHODS FOR ASSESSING THE COMPETITIVENESS OF EDUCATIONAL ACTIVITIES OF UNIVERSITIES WITHIN THEIR INFORMATION ENVIRONMENTS**

### **3.1. Formation of information environments of universities**

To take into account the full range of educational activities of universities, it is necessary to form an information environment that will contain the necessary information to be used to calculate the competitiveness assessment.

The information environment of a university is a set of systems, resources, tools and technologies that ensure the exchange, storage, processing and access to information in the university environment. This includes a variety of information technologies, databases, networks, electronic resources, programs for learning and administration, as well as cybersecurity tools. The university information environment is essential for the effective functioning of the university, teaching and research.

The formation of university information environments is the process of creating and maintaining a system of access to information that helps students, teachers, researchers and staff to obtain the necessary data for study, training, research and administration.

The main stages of the formation of university information environments are:

1. The university should create a strong infrastructure, including computer networks, servers, databases, software, etc. This will ensure fast and reliable access to information.

2. The availability of effective communication channels is an important aspect of the formation of information environments. The use of e-mail, websites, chat systems and other tools allows students and teachers to exchange information, communicate and collaborate with each other.

3. The university should provide access to electronic resources, such as digital libraries, journals, databases, and other information retrieval tools. This

allows students and faculty to quickly obtain relevant and reliable information for their study and research needs.

4. The university should provide training and support in the use of information resources. This includes conducting educational seminars, workshops and consultations on how to find and use information.

5. Ensuring the security of information is a key aspect of the formation of the information environment. The university should develop a policy for the protection of confidential information, data backup and protection against cyber attacks.

In order to build information environments, we will consider universities or higher education institutions and their structural units engaged in educational activities: institutes, faculties, departments, training centers, etc. In this context, the task of quantifying the competitiveness of educational activities arises. Each university is represented by an identification model and the information environment in which it operates.

The organizational and functional structure of the subjects of scientific activity as an organization is a set of relations that establish the ordering, regulation, coordination of scientific activities of the subjects to achieve its goals, in particular, to increase the efficiency of scientific research and its potential.

Let

$$A = \{ a_1, a_2, \dots, a_n \} \quad (3.1)$$

– is the set of teachers who teach certain disciplines at universities and are active representatives of the university environment,  $n$  is the number of teachers.

Let

$$H = \{ h_1, h_2, \dots, h_m \} \quad (3.2)$$

– is the set of disciplines taught by teachers from set  $A$ ,  $m$  is the number of disciplines.

Suppose that the set of all pairs between the elements of  $A$  and  $H$

$$A \times H = \{(a, h) \mid a \in A \wedge h \in H\} \quad (3.3)$$

and the binary relation  $U \subset A \times H$ , what defines a teacher of the discipline  $h \in H$

The set of all disciplines of a teacher at time  $t$  is denoted by

$$H(a_i, t) = \{h_j \in H \mid (a_i, h_j) \in U, t \in T\}, i = \overline{1, n}, j = \overline{1, m}. \quad (3.4)$$

For each discipline  $h \in H$  define the set of its teachers

$$A(h_j) = \{a_i \in A \mid (a_i, h_j) \in U\}, i = \overline{1, n}, j = \overline{1, m}. \quad (3.5)$$

Let

$$P = \{p_1, p_2, \dots, p_k\} \quad (3.6)$$

– is the set of publications published by teachers from set  $A$ ,  $k$  – number of publications.

Suppose that the set of all pairs between the elements of  $A$  and  $P$

$$A \times P = \{(a, p) \mid a \in A \wedge p \in P\} \quad (3.7)$$

and the binary relation  $\overline{U} \subset A \times P$ , what defines a teacher of the discipline  $p \in P$ .

We also define a binary relation  $C \subset P \times P$ , defining the citation of all publications  $p \in P$ ,

$$P \times P = \{(p_i, p_j) \mid p_i, p_j \in P, i \neq j\}. \quad (3.8)$$

The set of all publications of the teacher  $a \in A$  at time  $t$  is denoted by

$$P(a_i, t) = \{p_j \in P \mid (a_i, p_j) \in \overline{U}, t \in T\}, i = \overline{1, n}, j = \overline{1, k}. \quad (3.9)$$

For each publication  $p \in P$  define the set of its authors

$$A(p_j) = \{a_i \in A \mid (a_i, p_j) \in \overline{U}\}, i = \overline{1, n}, j = \overline{1, k}.$$

A scalar assessment of a teacher's competitiveness is a kind of functional reflection:

$$\Phi: A \rightarrow \mathbb{R}, \quad (3.10)$$

where  $\mathbb{R}$  – is a set of real numbers.

A university professor at time  $t$  is represented by a set of identifiers that define his or her educational and research activities:

$$K(a_i, t) = (P(a_i, t), H(a_i, t), S(a_i, t), Q^A(a_i, t), \Phi(a_i, t), M(a_i, t)), \quad (3.11)$$

where  $P(a_i, t)$  – is the set of publications by teacher  $a_i$  at time  $t$ ;

$H(a_i, t)$  – is the set of disciplines taught by teacher  $a_i$  at time  $t$ ;

$S(a_i, t)$  – a set of refresher courses,  $a_i$  teacher certification at a point in time  $t$ ;

$\Phi(a_i, t)$  – is an assessment of the scientific potential of a teacher  $a_i$  at time  $t$ , the Hirsch index or another index of scientific productivity;

$M(a_i, t)$  – is the number of international projects in which teacher  $a_i$  participates at time  $t$ .

Let

$$U = \{u_1, u_2, \dots, u_z\} \quad (3.12)$$

– is the set of universities employing teachers from the set  $A$ ,  $z$  – number of universities.

The university information environment is represented by a set of identifiers:

$$K(u_i, t) = (E_1(u_i, t), E_2(u_i, t), E_3(u_i, t), E_4(u_i, t), E_5(u_i, t)), \quad (3.13)$$

where  $E_1(u_i, t)$  – normalized assessment of  $u_i$  international activity at a point in time  $t$ ;

$E_2(u_i, t)$  – is a normalized estimate of the student contingent of university  $u_i$  at time  $t$ ;

$E_3(u_i, t)$  – is a normalized estimate of the scientific or teaching staff of the university  $u_i$  at time  $t$ ;

$E_4(u_i, t)$  – is a normalized quantitative assessment of the university's research activities at time  $t$ ;

$E_5(u_i, t)$  – is a normalized estimate of the university's resource provision at time  $t$ .

The definition of the information environment of a university is not necessarily related to these identifiers only. However, taking into account the main parameters, it is possible to calculate the tasks aimed at improving the efficiency of the organization of educational activities and increasing the competitiveness of the university.

The international activity of a university refers to its engagement in global initiatives, collaborations, and partnerships that extend beyond national borders. This involvement can take various forms and is essential for fostering academic exchange, research collaboration, cultural diversity, and the development of a global perspective. Here are key aspects of a university's international activity:

1. **International Partnerships.** Establishing partnerships with universities and educational institutions worldwide for student and faculty exchange programs, joint research projects, and collaborative academic programs. Engaging in joint research initiatives with international partners to address global challenges and contribute to the advancement of knowledge.

2. **Student and Faculty Mobility.** Facilitating student and faculty exchange programs to allow for academic and cultural immersion in partner institutions. Hosting scholars from other countries and sending faculty members abroad for sabbaticals, workshops, and collaborative research.

3. **International Conferences and Events.** Organizing conferences and events that attract participants and presenters from around the world, fostering knowledge exchange and networking. Encouraging faculty and students to participate in international conferences, seminars, and workshops to showcase research and build global networks.

4. **Dual Degree Programs.** Collaborating with foreign universities to offer dual degree programs that allow students to earn degrees from both

institutions. Developing joint academic programs with international partners to provide students with a diverse and global educational experience.

5. Cultural Exchange Programs. Facilitating cultural exchange programs, language immersion courses, and international internship opportunities to enhance students' cross-cultural understanding. Providing support services for international students, including orientation programs, language support, and assistance with adapting to a new academic and cultural environment.

6. Global Research Initiatives. Establishing collaborative research centers that address global challenges and involve researchers from different countries. Joining international research networks and consortia to leverage expertise, share resources, and address complex global issues.

7. Language Programs and Support. Offering language programs that enable students and faculty to acquire proficiency in commonly used international languages. Providing language support services for international students and scholars, including translation and interpretation services.

8. International Outreach and Recruitment. Actively recruiting international students and faculty members to enhance diversity and bring a global perspective to the campus community. Promoting the university globally through marketing and branding initiatives to attract a diverse and talented pool of students and faculty.

9. Global Engagement in Social Issues. Participating in global initiatives and projects aimed at addressing social issues, promoting sustainable development, and contributing to the global community. Engaging in international humanitarian efforts and outreach programs that positively impact communities worldwide.

10. Global Alumni Network. Nurturing a strong global alumni network to facilitate ongoing connections and collaborations among graduates around the world. Organizing international alumni events and establishing alumni chapters in different regions to foster continued engagement.

11. International Accreditation and Recognition. Pursuing and maintaining international accreditations to enhance the university's global reputation and recognition. Ensuring that academic qualifications are recognized internationally, facilitating student and faculty mobility.

12. Internationalization of the Curriculum. Integrating global perspectives into the curriculum to prepare students for a globally interconnected world. Offering programs and initiatives that enhance students' cross-cultural competency and global awareness.

Assessing the resource provision of a university involves evaluating the availability and adequacy of various resources necessary for its functioning. These resources can be broadly categorized into financial, human, physical, and technological resources. Below are key considerations for estimating a university's resource provision:

1. Financial resources. Review the university's annual budget to understand how funds are allocated across departments, academic programs, research initiatives, and infrastructure development. Assess the availability of endowments, grants, and philanthropic contributions that contribute to the financial health of the institution. Analyze the structure of tuition fees and other charges to understand how these contribute to the overall revenue stream.

2. Human resources. Evaluate the ratio of faculty members to students to gauge the institution's commitment to providing personalized and quality education. Assess the number and qualifications of administrative and support staff to ensure efficient university operations. Consider the academic qualifications, research expertise, and diversity of the faculty to determine the strength of the teaching and research workforce.

3. Physical resources. Evaluate the quality and adequacy of classroom spaces, laboratories, libraries, recreational facilities, and student housing. Consider the maintenance and upkeep of infrastructure to ensure a safe and conducive learning environment. Review any ongoing or planned construction projects to

accommodate growth and improve facilities.

4. Technological resources. Assess the availability and sophistication of IT infrastructure, including networks, computer labs, and online learning platforms. Evaluate the availability of specialized equipment and technology to support research initiatives across various disciplines. Consider the integration of digital tools and resources in teaching and learning, including e-learning platforms and educational technologies.

5. Library resources. Evaluate the size and diversity of the university library's collection, including books, journals, and digital resources. Assess the availability of library services such as research assistance, interlibrary loans, and access to online databases. Consider the integration of technology within the library, including digital catalog systems and online research tools.

6. Research and innovation. Assess the availability of funding for research projects and initiatives undertaken by faculty and students. Evaluate the quality and accessibility of laboratories and research centers that support scientific and academic research. Consider the university's engagement in research collaborations with industry partners, other institutions, and research organizations.

7. Student support services. Evaluate the availability of counseling, mental health, and medical services to support student well-being. Assess the effectiveness of career counseling, internship placements, and job placement support for students. Consider the variety and vibrancy of student clubs, organizations, and extracurricular activities.

8. Accessibility and inclusivity. Assess the availability and accessibility of financial aid, scholarships, and grants to support students from diverse socio-economic backgrounds. Consider the existence of policies and initiatives that promote diversity, equity, and inclusion within the university community.

9. Quality assurance and accreditation. Review the university's accreditation status to ensure that it meets or exceeds established academic standards. Assess the presence of quality assurance mechanisms, such as internal

and external reviews, to maintain and improve educational standards.

10. Community and industry engagement. Evaluate the university's engagement with the local community through outreach programs, community service, and partnerships. Assess collaborations with industry partners for internships, research projects, and workforce development.

11. Sustainability initiatives. Evaluate the university's commitment to sustainability through eco-friendly practices, waste reduction, and energy-efficient initiatives. Consider the institution's engagement in social responsibility initiatives, community development, and ethical practices.

12. Governance and leadership. Assess the effectiveness of university leadership in strategic planning, resource allocation, and fostering a positive institutional culture. Review the transparency and inclusivity of governance structures, including decision-making processes and stakeholder involvement.

Knowledge of university identifiers at a certain point in time  $t_v$ , and the values of the identifiers at the time  $t_{v-x}$ ,  $X = \overline{1, x}$ ,  $t_0$  – the initial moment of time, form the information environment of the university. The set of values of teacher identifiers  $a_i$  is represented as follows:

$$(K(a_i, t_0), K(a_i, t_1), \dots, K(a_i, t_{v-1}), K(a_i, t_v)). \quad (3.14)$$

The set of values of university identifiers  $u_i$  is represented as follows:

$$(K(u_i, t_0), K(u_i, t_1), \dots, K(u_i, t_{v-1}), K(u_i, t_v)). \quad (3.15)$$

These identifiers will be used to obtain competitiveness scores for universities.

### **3.2. Method for assessing the competitiveness of educational activities of universities, including their information environment**

Assessing the competitiveness of universities' educational activities is a complex process that involves the analysis of various parameters and criteria. The

most common methods of evaluating universities are rating systems that are used both internationally and nationally.

One of the most famous international rankings is the QS World University Rankings. It evaluates universities based on such criteria as academic reputation, reputation among employers, number of citations of scientific publications, teacher-to-student ratio, international cooperation, etc. Many countries also have national university rankings that take into account the specifics of the educational system and national priorities. They also use different indicators to assess the competitiveness of universities in their countries.

Assessing the competitiveness of universities may also include examining the structure of courses, the presence of innovations, the level of interaction with industry, and the proportion of graduates who find work in their field. It is important to note that assessing a university's competitiveness is a complex process that may have certain limitations and drawbacks. For example, certain rankings may be subjective or not sufficiently take into account the unique characteristics of each university. Therefore, it is important to take into account various sources and make a full analytical assessment of the university's competitiveness.

The development of the information educational and scientific space of any country is an extremely important factor that contributes to its prestige, economic development and the emergence of new technologies in various spheres of human activity. In recent decades, researchers have focused their attention on creating mechanisms for effective management of the development of the educational and scientific space. This can be achieved through the involvement of private organizations and financial support from government agencies at various levels, as well as the expansion of international cooperation through research and education projects such as Horizon 2020 and Erasmus+. Therefore, private companies interested in the development of scientific and technological technologies and foreign partners are faced with the important task of creating effective criteria for assessing the competitiveness of research activities of scientists, universities, and

their structural units, such as departments, faculties, and institutes.

Let us consider the methods of assessing the productivity of research activities of organizations. Global methods for evaluating higher education institutions include such popular tools as the World University Rankings developed by Quacquarelli Symonds (QS ranking) and the Academic Ranking of World Universities, known as the Shanghai Ranking. The QS ranking provides a comprehensive assessment of the performance of higher education institutions, taking into account both objective and subjective indicators. The Shanghai Ranking includes only those institutions whose graduates have won Nobel or Fields Prizes.

Additionally, the aspect of representation of institutions in the web space is assessed by the Ranking Web of Universities methodology. Along with international rankings, there are national ones, such as the Top 200 Ukraine ranking by osvita.ua, which takes into account investments in startups and other parameters. The indicators that are taken into account when calculating the ranking and their relative importance are shown in the tables below. The Webometrics ranking assesses the presence and influence of universities in the web space, going beyond bibliometric indicators and focusing on social, cultural, environmental and political aspects of their activities.

Having information about the state of the university's information environment, it is possible to determine the university's competitiveness through the rate of change of university identifiers:

$$O(u_i, b) = \frac{1}{5} \sum_{j=1}^5 \frac{E_j(u_i, t_v) - E_j(u_i, t_{v-b})}{E_j(u_i, t_{v-b})} \cdot 100\%, \quad (3.16)$$

where  $O(u_i, b)$  – rate of change of university identifiers  $u_i$  at a given time  $t_v$  relative to a point in time  $t_b$  or the competitiveness of the university  $u_i$ .

The issue of choosing the value of the parameter  $b$  is a separate research task and is determined empirically. This requires a detailed assessment for different

values of the parameter  $b$ . For verification, the value of the parameter  $b=5$  was chosen.

Similarly, for teachers, competitiveness indicators are determined by formulas:

$$\begin{aligned} \bar{O}(a_i, b) = & \frac{P(a_i, t_v) - P(a_i, t_{v-b})}{P(a_i, t_{v-b})} + \frac{H(a_i, t_v) - H(a_i, t_{v-b})}{H(a_i, t_{v-b})} + \frac{S(a_i, t_v) - S(a_i, t_{v-b})}{S(a_i, t_{v-b})} + \\ & + \frac{Q^A(a_i, t_v) - Q^A(a_i, t_{v-b})}{Q^A(a_i, t_{v-b})} + \frac{\Phi(a_i, t_v) - \Phi(a_i, t_{v-b})}{\Phi(a_i, t_{v-b})} + \frac{M(a_i, t_v) - M(a_i, t_{v-b})}{M(a_i, t_{v-b})} \\ O(a_i, b) = & \frac{\bar{O}(a_i, b)}{6} \cdot 100\%, \end{aligned} \quad (3.17)$$

where  $O(a_i, b)$  – rate of change of teacher identifiers  $a_i$  at a given time  $t_v$  relative to a point in time  $t_b$ .

If the competitiveness of teachers is positive and growing, then the competitiveness of the universities where they work is also positive and growing. The information environment of the university is changing, sometimes quite intensively, and this should be taken into account in the assessment of competitiveness.

To build a vector assessment of the competitiveness of teachers, we will set, on the basis of the indicators of the university environment identifiers

$$K(a_i, t) = (P(a_i, t), H(a_i, t), S(a_i, t), Q^A(a_i, t), \Phi(a_i, t), M(a_i, t)). \quad (3.18)$$

Next, you can choose the 6-dimensional space score that is the best in terms of achieving maximum efficiency or effectiveness for the corresponding index:

$$P_{\max} \geq \max_{i=1, n} \max_{j=0, v} (P(a_i, t_j)), \quad (3.19)$$

$$H_{\max} \geq \max_{i=1, n} \max_{j=0, v} (H(a_i, t_j)), \quad (3.20)$$

$$S_{\max} \geq \max_{i=1, n} \max_{j=0, v} (S(a_i, t_j)), \quad (3.21)$$

$$Q^A_{\max} \geq \max_{i=1, n} \max_{j=0, v} (Q^A(a_i, t_j)), \quad (3.22)$$

$$\Phi_{\max} \geq \max_{i=1,n} \max_{j=0,v} (\Phi(a_i, t_j)), \quad (3.23)$$

$$M_{\max} \geq \max_{i=1,n} \max_{j=0,v} (M(a_i, t_j)), \quad (3.24)$$

where  $P_{\max}$ ,  $H_{\max}$ ,  $Q^A_{\max}$ ,  $S_{\max}$ ,  $\Phi_{\max}$ ,  $M_{\max}$  - the maximum competitiveness scores for all employees in the database for the entire period of observation. Then we will get a score that is the ideal assessment of an employee's competitiveness. This is the score that any employee needs to achieve, and his or her competitiveness will be calculated from achieving the appropriate level of the maximum score:

$$K_{\max} = (P_{\max}, H_{\max}, S_{\max}, Q^A_{\max}, \Phi_{\max}, M_{\max}). \quad (3.25)$$

The closeness of a teacher's grades at a given time to the maximum is determined based on the following metrics,  $i = \overline{1, n}$ :

$$\begin{aligned} \rho^+(K(a_i, t_v)) &= |P(a_i, t_v) - P_{\max}|^d + |H(a_i, t_v) - H_{\max}|^d + |S(a_i, t_v) - S_{\max}|^d + \\ &+ |Q^A(a_i, t_v) - Q^A_{\max}|^d + |\Phi(a_i, t_v) - \Phi_{\max}|^d + |M(a_i, t_v) - M_{\max}|^d, \\ \rho(K(a_i, t_v)) &= (\rho^+(K(a_i, t_v)))^{\frac{1}{d}}, \end{aligned} \quad (3.26)$$

– Minkowski distance,  $d > 2$ ,  $d \in \mathbb{N}$ ,  $\mathbb{N}$  – a set of positive integers.

The described method of assessing teacher competitiveness takes into account metric distances and allows you to build integral scores  $\rho(K(a_i, t_d))$  for a particular teacher  $a_i$ . These scores are determined by the closeness of the score vector to the so-called maximum point. In addition to the scores  $\rho(K(a_i, t_d))$  Other metric distances can be used as an integral assessment of competitiveness. These metric distances must satisfy the following conditions: symmetry, constancy under self-similarity, non-negativity, and the triangle rule.

This score can also be used as an average to determine the university's integral score. If  $A = \{a_1, a_2, \dots, a_n\}$  - a set of university teachers  $u^*$ , then the integral score of the university can be represented by the formula:

$$\rho\left(\mathbf{K}\left(\mathbf{u}^*, t_v\right)\right)=\frac{1}{n} \sum_{i=1}^n\left(\rho^+\left(\mathbf{K}\left(\mathbf{a}_i, t_v\right)\right)\right)^{\frac{1}{d}} . \quad (3.27)$$

Let's consider another method. To build a vector assessment of the competitiveness of universities, let us set the following indicators of university environment identifiers:

$$\mathbf{K}\left(\mathbf{u}_i, t\right)=\left(E_1\left(\mathbf{u}_i, t\right), E_2\left(\mathbf{u}_i, t\right), E_3\left(\mathbf{u}_i, t\right), E_4\left(\mathbf{u}_i, t\right), E_5\left(\mathbf{u}_i, t\right)\right) . \quad (3.28)$$

Next, you can select the 5-dimensional space score that is the best in terms of achieving maximum efficiency or effectiveness for the corresponding index:

$$E_j^{\max} \geq \max_{i=1, n} \max_{j=0, v}\left(E_j\left(\mathbf{u}_i, t_j\right)\right), j=\overline{1, 5} \quad (3.29)$$

where  $E_j^{\max}$  - maximum competitiveness scores for all universities in the database for the entire period of observation. Then we will get a score that is an ideal estimate of the university's competitiveness. This is the score that any university needs to achieve, and its competitiveness will be calculated from achieving the corresponding level of the maximum score:

$$\mathbf{K}_{\max}=\left(E_1^{\max}, E_2^{\max}, E_3^{\max}, E_4^{\max}, E_5^{\max}\right) . \quad (3.30)$$

Closeness of university grades at a given time  $t_v$  to the maximum is determined based on metrics,  $i=\overline{1, n}$ :

$$\beta^+\left(\mathbf{K}\left(\mathbf{u}_i, t_v\right)\right)=\sum_{j=1}^5\left|E_j\left(\mathbf{u}_i, t_v\right)-E_j^{\max}\right|^d ,$$

$$\beta\left(\mathbf{K}\left(\mathbf{u}_i, t_v\right)\right)=\left(\beta^+\left(\mathbf{K}\left(\mathbf{u}_i, t_v\right)\right)\right)^{\frac{1}{d}} \quad (3.31)$$

– Minkowski distance to determine the integral assessment of university competitiveness,  $d>2$ ,  $d \in \mathbb{N}$ ,  $\mathbb{N}$  – is a set of positive integers.

### 3.3. Dynamics of changes in the information environment of the university and comprehensive assessment of competitiveness

The information environment changes over time, namely, the values of the

parameters of the information environment identifiers change. For example, a university has won grants for international projects, so its M score will increase and its competitiveness score will immediately increase. In order to see the dynamics of changes in the university's competitiveness, it is necessary to build a time series of integral scores:

$$\left(\beta(K(u_i, t_1)), \beta(K(u_i, t_2)), \dots, \beta(K(u_i, t_v))\right). \quad (3.32)$$

Having such a time series, we can make a forecast of competitiveness for the next period of time. If the value in the university's information environment changes quarterly, we can make a forecast with a horizon of 4 and we get a forecast of changes in competitiveness for the year. This is enough to draw a conclusion about the development of the university. However, it should be noted that the models chosen for forecasting must meet the requirements. It is important that the models adequately reflect the actual data. The data may be weakly persistent or random, in which case the appropriate classes of forecasting models should be used.

In general, to get a preliminary conclusion about the dynamics of changes in the competitiveness of the university, it is enough to use the traditional moving average model. That is, the forecast with period 1 is calculated by the formula:

$$\beta(K(u_i, t_{v+1})) = \frac{1}{p} \sum_{j=1}^p \beta(K(u_i, t_{v-j+1})), \quad (3.33)$$

where  $\beta(K(u_i, t_{v+1}))$  - forecast of university competitiveness  $u_i$  with the horizon - one.

Such an assessment makes it possible to determine the direction of the university's development and direct funding from the ministry or local budget in the right direction. In general, forecasting the university's educational performance is an important step in the strategic management of the institution. Different methods and approaches can be used to make forecasts. In addition to the above method, the university information environment can include a large number of

indicators, i.e. the environment is expandable. The described methods of assessing competitiveness allow to include a large number of indicators in the information environment of the university that are significant in the calculation of competitiveness and can be used for forecasting. However, it is important that all indicators are obtained from open data. The following approaches can be used for forecasting:

1. Analysis of historical data. A careful analysis of past years allows us to identify trends and patterns in the development of the university's educational activities.

2. Demographic and socio-cultural factors. Consideration of population dynamics, changes in the socio-cultural environment and other demographic parameters helps to predict changes in the demand for educational services.

3. Technological innovations. Taking into account and assessing the impact of new technologies in education helps to predict their contribution to the development of the university.

4. Labor market needs. Understanding the needs of the labor market and trends in the choice of professions can determine the direction of curriculum development.

5. Management effectiveness. Evaluation of internal processes and management activities affects the overall efficiency of the university and can serve as a basis for forecasting.

6. Attracting students. Analysis of changes in the number and quality of applicants allows the university to adapt its strategy to attract and retain students.

7. Global and regional trends. Taking into account global and regional trends in education can provide context for forecasting.

8. Reporting and evaluation of results. The systematic collection and evaluation of educational outcomes helps to identify improvements and adjust the university's strategy.

The use of models for forecasting the university's educational performance

can greatly facilitate the strategic management of the institution. Below are recommendations for the effective use of such models:

1. Define the goals of forecasting. Clarify the purpose of forecasting - whether it is a forecast of student enrollment, changes in academic performance, development of new programs, or other aspects of educational activities. Clear goals help to select appropriate models and indicators.

2. Collect and prepare data. Create a database that includes historical data from the educational sphere, such as the number of students, academic performance, financial indicators, rankings, and other factors that affect the university's activities.

3. Selection of forecasting models. Consider the nature of the data and the specifics of the educational process when choosing models. You can use statistical methods, machine learning, or expert approaches depending on the task.

4. Evaluate the effectiveness of models. Periodically check and adapt the selected models based on their accuracy and ability to predict real changes in the educational environment.

5. Integration with other strategic tools. Ensure that forecasting models interact with other strategic management tools, such as budgeting, development planning, and strategy implementation monitoring.

6. Consideration of exogenous factors. Predict the impact of external factors, such as changes in legislation, social and economic trends, on the university's educational activities.

7. Automation of the forecasting process. Use information technology to automate data collection and processing, which will allow for faster and more efficient forecasting.

8. Sustainable improvement of models. Collect feedback from educational stakeholders, teachers, students, and other stakeholders to continuously improve forecasting models.

9. Ensure transparency and communication. Carefully explain the

forecasting methodology, results, and decisions made, ensuring mutual understanding and trust among all stakeholders.

10. Flexibility and adaptability. Be prepared to adapt the forecasts to changes in the socio-economic environment and internal parameters of the university.

### **Conclusions to chapter 3**

1. The article describes the formation of the university information environment as a process of creating and maintaining a system of access to information that helps students, teachers, researchers and staff to obtain the necessary data for study, training, research and administration. University information environments, as well as information environments of university staff and teachers, contain information about educational activities. In particular, the information environment of a teacher has information about scientific publications published by the teacher, disciplines taught by the teacher, advanced training courses, assessment of scientific potential, and participation in international educational and scientific projects. The university information environment includes information about the student population, assessment of the university's academic staff, resource support, etc.
2. The article describes a method for assessing the competitiveness of universities' educational activities, including their information environment. The method is based on the values of the identifiers of the information environment of the university and teachers. A comprehensive assessment allows to identify those areas of the university's educational activities that should be improved.
3. The method of forecasting the competitiveness of educational activities of universities, which takes into account the dynamics of changes in the indicators of the university information environment, is described.

Recommendations for the application of methods for predicting the competitiveness of university educational activities are also formed.

## **CHAPTER 4. A PROGRAM MODULE FOR ASSESSING THE COMPETITIVENESS OF THE UNIVERSITY'S EDUCATIONAL ACTIVITIES**

### **4.1. Modules for collecting information about the university's activities in order to assess its competitiveness**

In order to verify the developed methods and models, a database with information on 311700 scientific publications authored by 77898 Chinese scientists affiliated with various universities and colleges in China was collected. The scientific publications were categorized based on the topics covered in these publications. As there were many topics identified, they were grouped into 124 categories, each representing a broader topic, such as differential equations, agriculture, scientometric analysis, etc.

Information on the educational activities of five selected universities in China was also collected. This collection is a rather complicated task, since it includes a large amount of information about international work, the work of teachers, the creation of teaching materials, lecture courses for the disciplines they teach, etc.

The main difficulties that arise in the formation of research topics are:

1. To form a topic, it is necessary to have a sufficient amount of data on citations of scientific publications. Selecting all citations of publications is a difficult task, since if publications are downloaded from the Internet, it is necessary to parse the text of the bibliography, select authors, titles of publications and other bibliographic data from them and add them to the database correctly. In this case, bibliographies can often be recorded in different formats, may contain abbreviations, etc.

2. The collected information may include data related to an isolated topic with few publications and citations. In this case, the task is either to combine this topic with another one that is close to it, or to remove this mathematics from consideration.

3. The described tasks have considerable computational complexity.

Therefore, it is necessary to use information coding and indexing to facilitate access to data on scientific publications and other results of educational activities of teachers.

4. Another difficulty is that at certain stages of forming a database on the results of educational activities of teachers, it is necessary to involve experts. However, a balance should be organized, i.e., data should be selected transparently and from open sources, and on the other hand, data that do not meet the purpose of the study or are inaccurate should be excluded from consideration.

In order to conduct a comprehensive assessment of the competitiveness of universities, it is necessary to select indicators that would characterize various aspects of educational activities. An important task is to select indicators that can be obtained from reliable, verified open sources, including scientometric databases, ministry websites, statistics, universities, etc.

To build a method for a comprehensive assessment of the competitiveness of Chinese universities, 115 indicators were selected and grouped into five main categories that reflect the main aspects of higher education institutions: international activity, quality of student enrollment, quality of academic staff, quality of scientific and research activities, and resource provision of higher education institutions.

Some categories are divided into several subcategories. In total, 15 categories are identified. For example, Table 4.1 shows the main categories and some subcategories for assessing the educational activities of a university.

Relevant performance assessments can be used by rectors, deans, department heads and to analyze the effectiveness of educational activities. Timely monitoring of the dynamics of changes in the results of educational activities makes it possible, if necessary, to make appropriate adjustments to the strategy of the university, department, faculty to improve its effectiveness.

Table 4.1.

## Criteria for assessing university competitiveness

<b>№</b>	<b>Name of criterion</b>	<b>Unit of measurement</b>
1	2	3
1	Contingent of students, total	number
1.1.	Bachelor's degree	number
1.2.	Master's degree	number
1.3.	Doctoral studies	number
	Share of postgraduate programs Bachelor's/Master's+Doctoral (1.2.+1.3.)*100/1	%
2	Number of teaching staff and researchers, total	number
2.1.	With degree (2.1.1.+2.1.2.+2.1.3.)	number
2.1.1.	With PhD degree	number
2.1.2.	With degree Candidate of Sciences	number
2.1.3.	With academic degree Doctor of Science	number
2.2.	With academic degree Master of Science	number
2.3.	Without degree	number
	Residency (2.1.*100)/2	%
	Contingent/PPS ratio	number
	Average time of awarding a degree after completion of doctoral studies	
3.	Number of articles published by the organization's employees in indexed international journals, total (3.1.+3.2.)	number
3.1.	In Web of Science database	number
3.1.1.	Q1	number
3.1.2.	Q2	number
3.1.3.	Q3	number

Continuation of Table 4.1.

1	2	3
3.1.4.	Q4	number
3.1.5.	In conference proceedings	number
3.2.	In Scopus database	number
3.2.1.	Q1	number
3.2.2.	Q2	number
3.2.3.	Q3	number
3.2.4.	Q4	number
3.2.5.	In conference proceedings	number
	Indexed articles per employee	number
	Share of articles with participation of students (undergraduates, masters, doctoral students)	%
4.	Citation rate of articles by university employees	number
4.1.	According to Web of Science database	number
4.2.	According to Scopus database	number
	Citation rate per one faculty member	number
5.	Number of articles published by employees of the organization in journals recommended by the authorized body	number
	Number of monographs by staff scientific-pedagogical and research workers of higher education institutions	number
	Articles in journals from item 5 per one employee (5/2)	number
	Share of articles from item 5, with participation of students (students, masters, doctoral students)	%
	Monographs per one employee	%
6	Publication of journals included in the international databases Web of Science, Scopus	number

Continuation of Table 4.1.

1	2	3
7	Publication of journals recommended by the authorized body	number
	Ratio of journals to employees	
8	Organization of scientific conferences, forums, the works of which are indexed in the international databases Web of Science, Scopus.	
9	Volume of external financing of research work under republican programs	monetary units
10	Amount of external financing of research work on international programs	monetary units
11	Amount of external funding of research work on regional programs	monetary units
12	University budget	monetary units
	Share of funds from research work in the total amount of the budget	%
	Funds from research work for each employee of the organization	monetary units
13	Number of holders of scientific scholarships for scientists who have made a certain contribution to the development of science	number
14	Number of holders of scientific scholarships for young scientists	number
15	Number of holders of scientific personalized prizes of the Ministry of China	number
	Share of employees from items 13,14,15 from the total amount of scientific research work	%

The educational component includes the contingent of students enrolled in bachelor's, master's, and doctoral programs. The student population is the total number of students enrolled in a particular higher education institution or in a

particular field of study. The number of students may differ for different levels of education, such as bachelor's, master's, and doctoral programs:

1. Bachelor's degree. This is the first level of higher education, which usually lasts 3-4 years. The bachelor's degree program includes students who acquire basic knowledge and skills in a chosen field.

2. Master's degree. This is the second level of higher education that provides deeper and more specialized knowledge. The duration of master's programs can vary from one to two years. The contingent of the master's program includes students who already have a bachelor's degree and wish to develop their competencies in a specific field.

3. Doctoral studies. This is the third level of higher education, which is designed to conduct research and gain a high level of expertise in a particular field. The contingent of doctoral studies includes students who have a master's degree and seek to achieve a high level of scientific development in their field.

The number and composition of the contingent may be determined by the policies and capabilities of a particular institution or country. There may also be different programs and specializations at each level of education that attract different groups of students.

The second criterion is the number of university faculty and staff with academic degrees and titles. The number of university professors with academic titles can vary considerably depending on a particular university, its size, faculties, and specializations. Different countries and universities have their own systems for awarding academic titles, and they may have different names and criteria. Universities may have academic titles such as professor, associate professor, senior lecturer, assistant professor, lecturer, etc. Usually, academic titles are awarded on the basis of education, scientific achievements, teaching experience, and other criteria. Some universities publish statistics on the number of teachers by their academic rank in their annual reports or on their websites. If you are interested in a particular university, I recommend that you refer to the official sources of this university or contact its administration to get accurate information.

The third criterion is the number of publications of teachers published in journals indexed in the Scopus and Web of Science databases. Both Scopus and Web of Science are databases for scientific publications, and they include works from various fields of knowledge. The number of published articles in these databases is constantly growing as scientists and researchers continue to contribute to various fields. To obtain up-to-date information on the number of articles published in specific journals and indexed in Scopus or Web of Science, you should use these databases themselves or use their interfaces to search for specific information.

The fourth criterion is the citation of scientific publications by other teachers. Citing scientific publications is the process of including references to a particular scientific work in another scientific work or publication. This process is important for scientific communication and determining the impact of a particular article or study in the scientific community. The main aspects of citation include the following:

1. Citation Index: The citation index is determined by the number of times a particular research paper has been cited by other papers. A large citation index can indicate the importance and impact of a study.

2. In-Text Citations: This is a reference to a specific source inserted directly into the text of a research paper. It usually includes the author's name and year of publication.

3. Bibliography: Every research paper usually has a section that lists all the sources used. This section is called a bibliography.

4. Citation indexes in databases: Databases such as Scopus, Web of Science, and Google Scholar keep records of citations of scientific papers. The citation index can be used to assess the impact of a particular author or publication.

The fifth criterion is the number of articles published by professors in special publications or the number of monographs, as well as relative indicators for universities.

The next criteria relate to the publication of journals at the university that are included in the Scopus and Web of Science databases, the publication of professional journals and collections of scientific papers at the university, the holding of scientific conferences, seminars, forums, etc.

The list also includes criteria for the amount of total funding for research and the total budget of the university, as well as the number of students and faculty members with research scholarships and some relative indicators.

There are several main categories of such a list. The first is the scientific category. To ensure the effectiveness of the assessment of the competitiveness of the university's educational activities, it is important to create a data warehouse, repository and electronic library to store these results. Scientometric databases are key tools for transforming knowledge and disseminating scientific results. Analysis of such databases allows us to evaluate the activities of scientists, alliances, universities, and even countries or regions. Among the various scientometric databases, Web of Science and Scopus are particularly reputable. Some major publishers also create their own commercial scientometric databases, such as Springer, Begell House Inc., Thomson Reuters (ISI), Web of Knowledge, Pleiades Publishing, Kluwer, and others. Among the non-commercial scientometric databases focused on technical sciences are COPERNICUS, BASE, DOAJ, Driver, FreeFullPDF, UlrichsWeb. Search engines, such as Publish or Perish and Google Academy, are also useful for evaluating the results of scientific activities.

The second major category is educational. One of the important components of assessing the competitiveness of a university's educational activities is the trust of applicants. It is expressed through the desire of applicants to enter the university. This indicator can be assessed by analyzing applicants' applications. The potential of university students can also be a separate parameter, which is basically the scores with which they entered the university, as well as other personal characteristics.

The potential of university students is determined by their abilities, motivation, interests, and ability to improve themselves. Here are some aspects that can influence the potential of university students:

1. Academic abilities. Students may have a high level of intelligence and ability in specific subject areas. Their success in school or previous education may indicate their ability to successfully learn new material at a higher level.

2. Motivation and goals. Students who have clear goals and strong motivation to pursue higher education can show great potential. Their desire to succeed can be a strong incentive to actively participate in university life and learning.

3. Independence and self-development. Students who are able to work independently, set themselves tasks and develop systematically can be more successful in the university environment.

4. Interests and hobbies. Interest in certain subject areas or fields of study can be an important factor affecting a student's success and commitment to studying the chosen field.

5. Social skills and communication skills. The ability to cooperate with other students, teachers and participate in group projects can also determine a student's potential in the university environment.

International component. The university's interaction with other universities abroad is extremely important. One of the most important is interaction within international programs. Information about the university's participation in programs can be found on the websites of these international projects and initiatives. The university's international activities are a wide range of initiatives and programs aimed at developing international relations, sharing knowledge and experience, and cooperating with universities and organizations from other countries. Here are some aspects of the university's international activities:

1. International mobility of students and teachers. Universities facilitate the exchange of students and faculty between different countries. This may include

exchange programs, joint double degrees, internships, and other forms of international mobility.

2. International programs and cooperation. Universities can develop joint international programs and research projects with other universities. This may include joint research, conferences, exhibitions, etc.

3. Support for international students. The university may provide services and support for international students, including language courses, adaptation programs, and counseling on studying and living in another country.

4. International conferences and events. The University may be active in organizing international scientific conferences, seminars, lectures and other events involving scientists and specialists from different countries.

5. Networks and associations. The University may participate in international academic networks and associations, facilitating the exchange of experience and resources.

To verify the described method of calculating the competitiveness of universities, we analyzed the activities and determined the relevant indicators of five Chinese universities:

1. Beijing University (Beij. Un.).
2. Shanghai University (Shan. Un.).
3. Nanjing University (Nank. Un.).
4. Wuhan University (Wuh. Un.).
5. Harbin Institute of Technology (Har. Un.).

The results are presented in Table 4.2.

For the calculation according to these criteria, we used normalized indicators that take values from 0 to 1. Also, for the convenience of perceiving the results, we scaled them with a multiplier of 100.

Table 4.2. Indicators of competitiveness  
of educational activities of some Chinese universities

Criterion	Universities				
	Beij. Un.	Shan. Un.	Nank. Un.	Wuh. Un.	Har. Un.
1	77.8	76.0	68.9	66.4	50.2
2	80.9	81.5	62.8	50.6	44.9
3	89.0	90.1	71.9	53.2	53.6
4	88.3	90.5	67.6	41.8	42.7
5	83.9	84.1	80.5	77.4	77.0
6	73.9	72.1	45.1	33.8	31.0
7	67.8	70.1	42.9	38.9	23.0
8	91.7	88.5	32.9	40.6	30.5
9	95.1	95.9	42.8	40.5	24.1
10	91.2	96.1	39.7	41.1	22.5
11	87.5	85.1	33.1	30.9	22.7
12	89.1	83.6	31.0	30.5	21.8
13	93.2	90.9	53.1	42.6	20.4
14	88.0	89.5	55.8	34.9	29.0
15	87.6	91.4	56.8	39.5	39.8
<b>Comprehensive assessment of university competitiveness</b>	<b>85.67</b>	<b>85.69</b>	<b>52.37</b>	<b>44.18</b>	<b>35.55</b>

Petal charts were constructed to see which of the criteria for these universities are approaching the best result and which need to be improved (Figures 4.1 - 4.5). If we take Shanghai University as the best or most competitive in this calculation,

and Harbin Institute of Technology as the least competitive, Figure 4.6 shows a joint diagram that shows which of the criteria the latter needs to improve.

The results obtained for Beijing University indicate that the item "volume of external financing of research work under republican programs" has the highest score, i.e., it is implemented at the university at the highest level compared to other criteria. The worst score was given to the item "publication of journals recommended by the authorized body". However, this score is relatively high compared to other university positions. Shanghai University also has the lowest score for the seventh criterion, and the highest for the ninth.

At Nanjing University, the lowest position is occupied by the university's budgeting, and the highest is the fifth criterion, "Number of articles published by employees of the organization in journals recommended by the authorized body." The situation is similar at Wuhan University: the budget is smaller than other universities, and the fifth criterion has the maximum values. At Harbin Institute of Technology, the thirteenth criterion is the least important, and the fifth criterion is the most important again. That is, the publication of articles in professional journals, a staff contract requirement, allows this criterion to be ranked high.

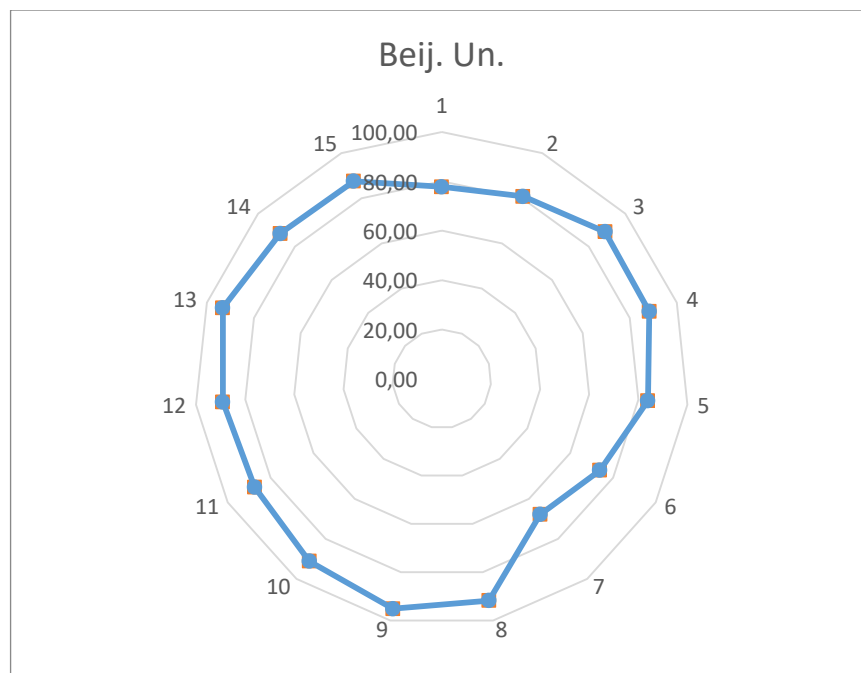


Figure 4.1 - Diagram of indicators of educational activity according to the specified criteria for calculating the competitiveness of Beijing University

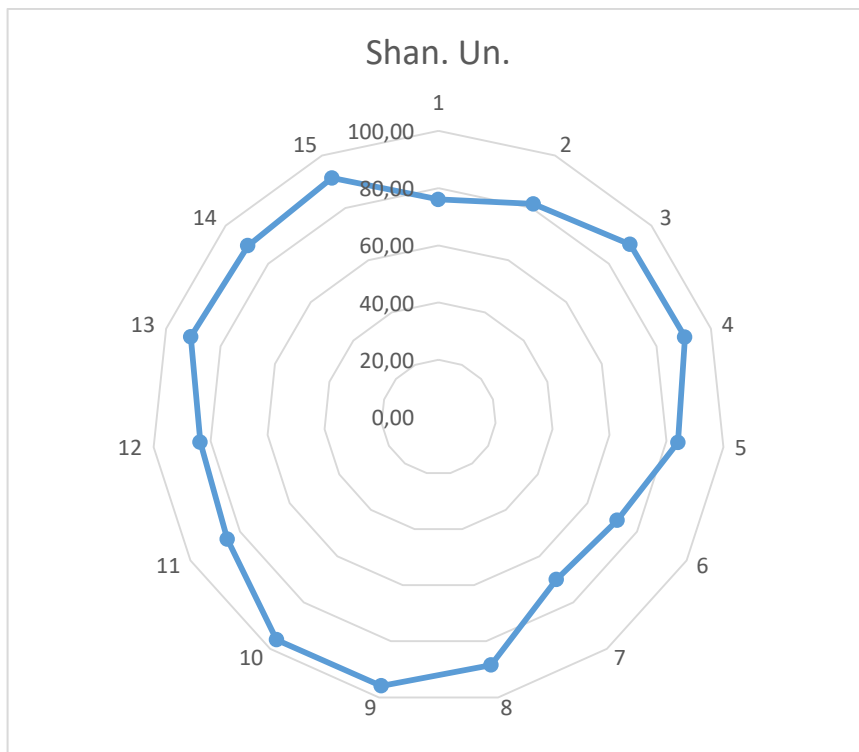


Figure 4.2 - Diagram of indicators of educational activity according to the specified criteria for calculating the competitiveness of Shanghai University

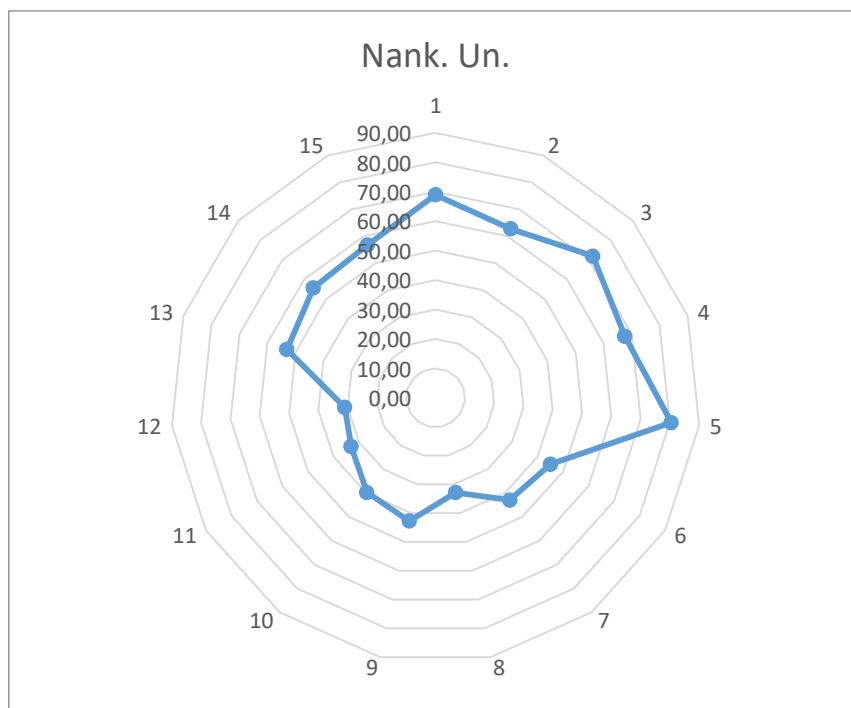


Figure 4.3 - Diagram of indicators of educational activity according to the specified criteria for calculating the competitiveness of Nanjing University

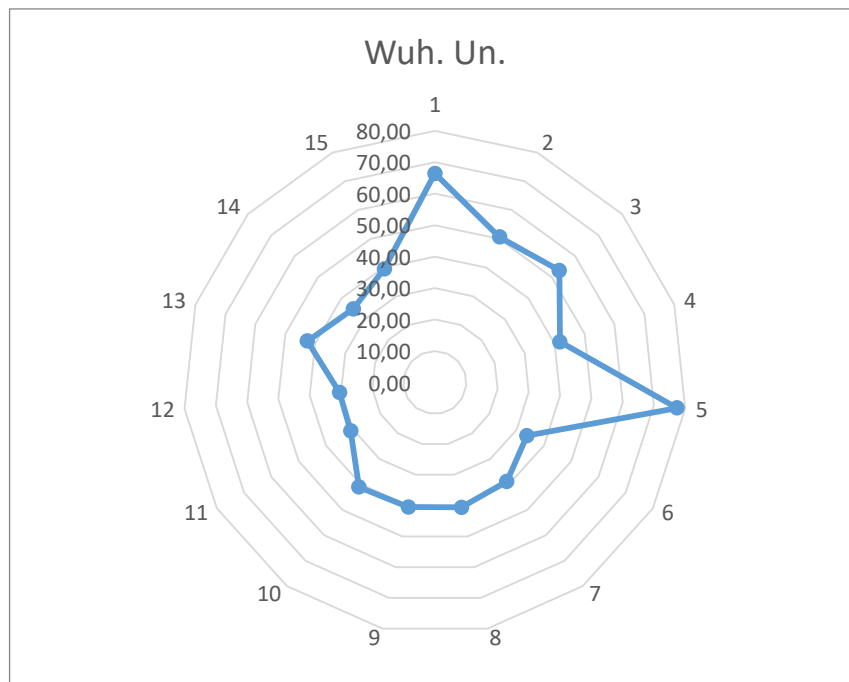


Figure 4.4 - Diagram of indicators of educational activity according to the specified criteria for calculating the competitiveness of Wuhan University

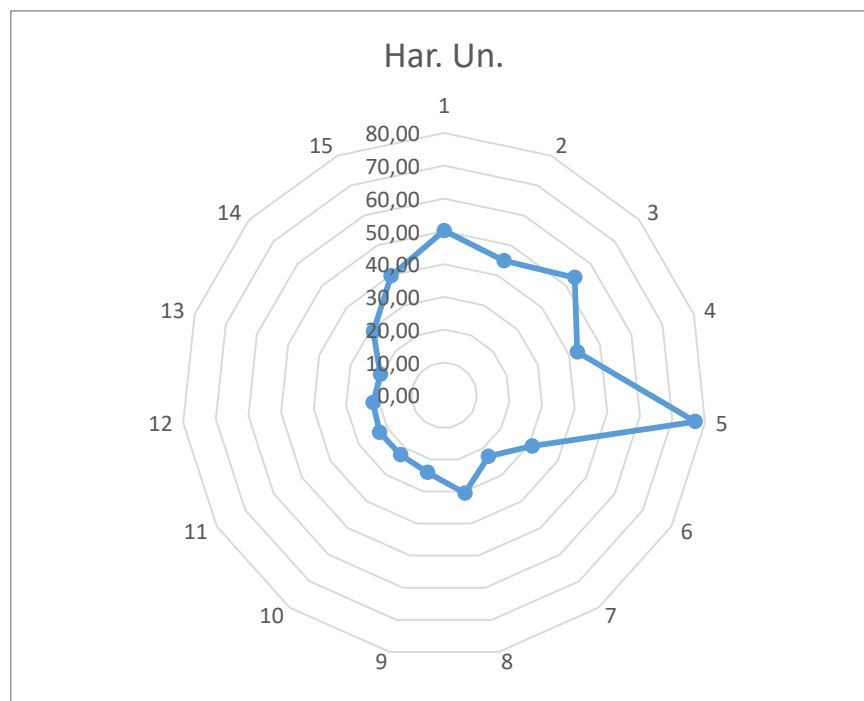


Figure 4.5. - Diagram of indicators of educational activity according to the specified criteria for calculating the competitiveness of the Harbin Institute of Technology

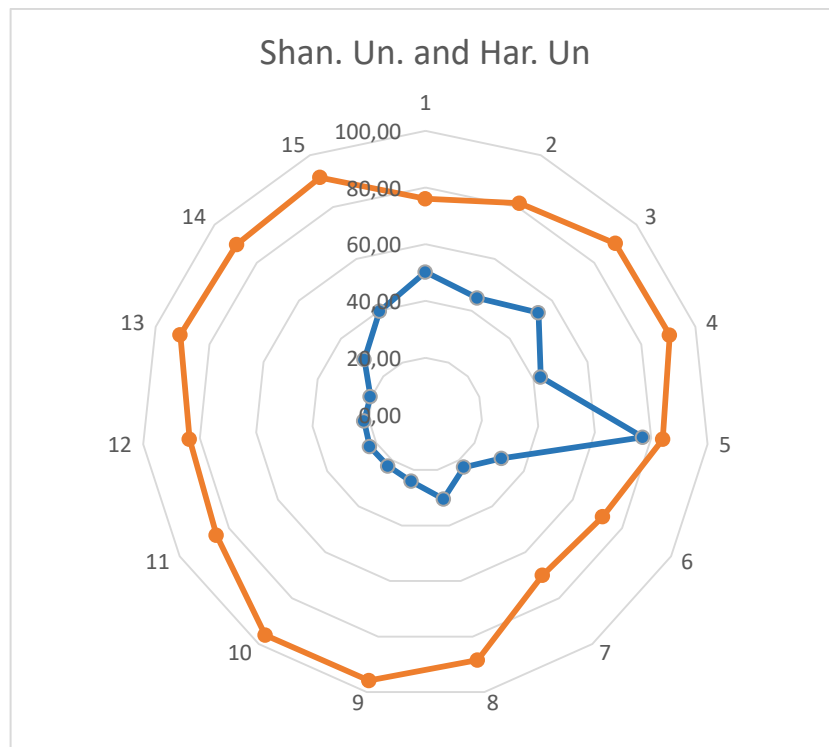


Figure 4.6 - Diagram of indicators of educational activity according to the specified criteria for calculating the competitiveness of the Harbin Institute of Technology (blue line) and Shanghai University (orange line).

According to the QS ranking, these universities are placed in the following places:

1. Beijing University (Beij. Un.) – 30.
2. Shanghai University (Shan. Un.) – 59.
3. Nanjing University (Nank. Un.) – 122.
4. Wuhan University (Wuh. Un.) – 257.
5. Harbin Institute of Technology (Har. Un.) – 285.

Accordingly, according to the method of calculating competitiveness described in this paper, only one position does not converge: Shanghai University is on the first place, Beijing University is on the second, and then the other positions of the universities coincide.

For a complete analysis of a university, in addition to the data presented, it is also necessary to calculate indicators for other types of activities. In particular, the

educational component should be analyzed more thoroughly, and student feedback on training and employment of students after graduation can be taken into account. Unfortunately, such indicators are not published in the public domain, so it is difficult to assess them for these universities.

To verify the results of the study, an information and analytical system was developed. This system incorporates methods that were previously proposed to assess the competitiveness of universities. When creating the system, the principles of distributed information systems development were used, which were defined in detail in the relevant work. The system also used components of the conceptual model of the automatic system described in the same document to determine the directions of research. There are 15 indicators for evaluation. The main focus of the information-analytical system was aimed at finding the results of educational activities. The results obtained make it possible to apply the method of assessing the competitiveness of the university.

Table 4.3

Interpretation of the results of the university competitiveness assessment

<b>Scale for assessing the competitiveness of the university's educational activities</b>	
<b>Meaning</b>	<b>Assessment</b>
(85,100]	E - Excellent
(50,85]	G - Good
(30,50]	F - Fair
(10,30]	P - Very poor
[0,10]	U - Unacceptable

Thus, according to the calculations for the universities, Beijing University (Beij. Un.), Shanghai University (Shan. Un.) belong to category E, Nanjing

University (Nank. Un.) belongs to category G on this scale, Wuhan University (Wuh. Un.) and Harbin Institute of Technology (Har. Un.) belong to category F. Table 4.4 shows the letter scores of universities' competitiveness.

According to the criterion of the number of maximum grades, Beijing University has the highest competitiveness, as Beijing University has 10 E grades and Shanghai University has 9 E grades. Other universities have no maximum grade.

Table 4.4. Indicators of competitiveness of educational activities of some Chinese universities

Criterion	Universities				
	Beij. Un.	Shan. Un.	Nank. Un.	Wuh. Un.	Har. Un.
1	G	G	G	G	G
2	G	G	G	G	F
3	E	E	G	G	G
4	E	E	G	F	F
5	G	G	G	G	G
6	G	G	F	F	F
7	G	G	F	F	P
8	E	E	F	F	F
9	E	E	F	F	P
10	E	E	F	F	P
11	E	E	F	F	P
12	E	G	F	F	P
13	E	E	G	F	P
14	E	E	G	F	P
15	E	E	G	F	F
<b>Comprehensive assessment of university competitiveness</b>	<b>E</b>	<b>E</b>	<b>G</b>	<b>F</b>	<b>F</b>

At Harbin Institute of Technology, seven criteria are rated P (very poor), and the administration should work on these criteria to improve the overall level of competitiveness. Some items are related; for example, the amount of budget funding will increase the number of published articles, as more qualified staff will

be attracted to participate in projects and publish scientific articles with a high impact factor.

The results are essential for a comprehensive assessment of the competitiveness of universities, taking into account various types of educational activities.

#### **4.2. Information system for assessing the competitiveness of educational activities of universities**

The functional-modular approach to the design of information technologies is generally recognized and tested in practice. An information model for assessing the competitiveness of educational activities is proposed.

It consists of four modules:

- Information collection module.
- Information storage module.
- Analysis module.
- Module of user interaction and data visualization.

The modular structure of this technology allows expanding and modifying the functionality of each module independently of other modules, increasing the stability and flexibility of the technology.

The information acquisition module is responsible for receiving incoming data and its primary processing. There are two possible sources of information: manual user input and automatic collection of public information.

Public information is information that is publicly available, free for use, distribution and modification. It can be information that is not restricted for exchange, access or use.

The main characteristics of open information include:

1. Accessibility. Open information should be easily accessible to all interested parties without restrictions or barriers.

2. Free use. The use of open information should be free and not limited by legal or technical restrictions.

3. Dissemination. Information may be freely distributed, as well as modified and used for various purposes.

4. No restrictions on use. Open information should have no restrictions on how it can be used.

Open information may include data, text, images, audio, video and other forms of information. This approach to information promotes openness, community development and innovation in various fields, including science, technology, education and civil society. An open source of information is a resource from which information can be freely used, distributed, and modified without restriction or charge. It can be any source that provides access to its information without copyright, technical barriers or legal restrictions. The best open sources of information needed to evaluate the results of scientific activity are scientometric databases. A scientometric database is a database that contains information about scientific publications, their citations, and other parameters used to measure the impact and visibility of research and authors. These databases help to analyze and compare the scientific contributions of different authors, institutions, journals, or countries.

The most important characteristics of information required for the proper functioning of a technology are reliability and integrity. Assessing the reliability of information is a complex task. One principle is that information is considered reliable until an inconsistency is detected. Another principle is that unverified information cannot be trusted.

Contradictory information is information about the state of an object or phenomenon at a certain point in time that comes from many very different sources. Verification of information is the process of confirming its authenticity. The main method of verification is to obtain information from reliable sources. Structured information is information about a particular object or phenomenon

presented as a set of pairs (property, value). Structuring is the process of converting unstructured information into structured information. Open information is usually available in an unstructured format. Information must be structured so that it can be stored and processed further. The information is sent to the storage module in a structured and reliable form.

The main task of the storage module is to store the information received from the information collection module. It also provides data collection in accordance with the requirements of the analysis module. The data collection module contains a database that is local to the other modules. The analysis module solves the main tasks of information technology for evaluating the results of scientific activities. These include determining the direction of scientific activity, assessing the competitiveness of educational activities, and forecasting the prospects for the development of scientific and pedagogical staff, universities and their structural units.

Considering a structural unit of a university as a set of individual subjects of scientific activity, the assessment of its scientific activity can be obtained as a vector or scalar convolution of the assessment of the results of scientific activity of its employees. An important idea when implementing the system of assessing the competitiveness of educational activities of universities was to ensure maximum openness and accessibility to the academic community. In addition, an important condition was to use only reliable and verified sources of information that do not involve subjective assessments and are recorded solely on the basis of the results of real research by universities. To ensure these provisions, a system architecture was created in which the interaction between the system and the user takes place via the Internet.

The block diagram of the information system for assessing the competitiveness of educational activities (Fig. 4.7) includes a module for collecting information, a module for processing information, a database, and a web server.

The target audience of system users is the Ministry of Education, university managers, etc.

The architecture of the information system should be represented by blocks that include separate microservices for the following tasks

- a complex for collecting, processing, and storing information on the competitiveness of universities;
- methods of forming research topics for teachers and university staff;
- methods for assessing the competitiveness of educational activities of universities.

The functional model of the information system for assessing the competitiveness of educational activities of universities consists of five main modules:

1. Manager, which is designed to perform tasks and interact with other services of the system.
2. Information collection service, which provides data from open sources and their preliminary processing.
3. Data storage service, which includes a database and methods of working with data.
4. Data analysis service, which includes methods of forming research topics, methods of assessing the competitiveness of educational activities; generating reports.
5. Visualization service that provides interaction with users through the WEB interface.

The infocommunication system for assessing the productivity of scientific activity is a combination of

- a web application that searches, stores and processes large amounts of information on the publication activity of scientists from the Internet;
- methods of information processing;

- sources of information (information on citations of teachers from scientometric databases);
- consumers of information (universities, research institutes, private companies, government agencies responsible for scientific policy).

The implementation of the service is characterized by the fact that its code is executed on a separate virtual server, and the interaction between the services is realized through the corresponding API. Information and requests are exchanged between services via local networks and the Internet. Data is transferred via the https protocol by sending a properly formatted POST request.

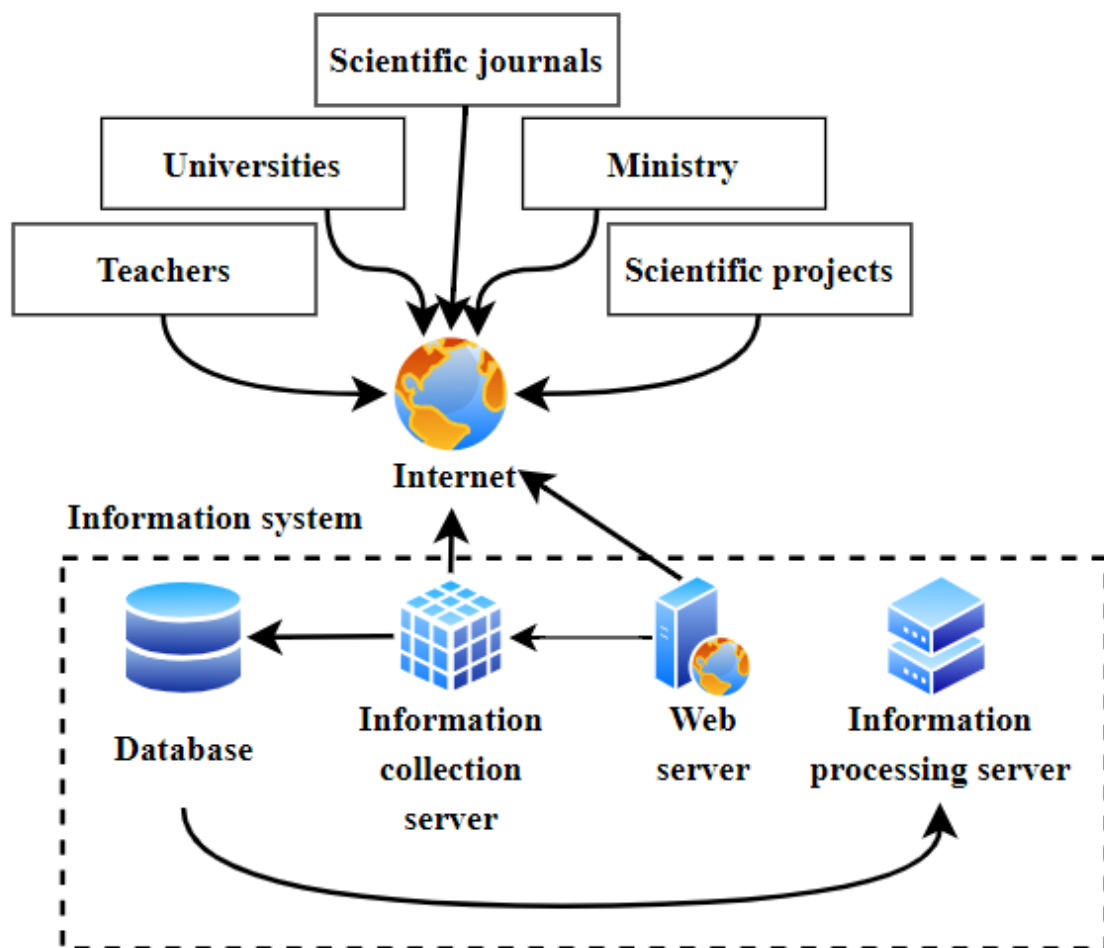


Figure 4.7. - Block diagram of the information system for assessing the competitiveness of educational activities of universities

Figure 4.7 shows a block diagram of the system for assessing the competitiveness of university educational activities. It consists of a database, an information collection server, a web server, an information offering server, and information sources: universities, teachers, scientific journals, the ministry, research projects, etc.

Creating a database on a university's educational activities is a complex task, as it must cover various aspects of management, statistics, and analytics. Below is a general structure of a database that can be used to store and process information about the university's educational activities. It is only a general concept and the specific structure may depend on the unique needs of the university.

Table "Students":

- StudentID (unique student identifier);
- First name;
- Surname;
- Date of birth;
- Address;
- Contact information;
- Level of study (bachelor's, master's, postgraduate);
- Specialty/Faculty;
- Degree/Course;
- Other personal data;

Table "Subjects and Courses":

- CourseID (unique course identifier);
- Course name;
- Description;
- Faculty;
- Teacher(s);
- Duration;
- Results of exams/grades;

Table "Teachers":

- TeacherID (unique teacher identifier);
- First name;
- Last name;
- Faculty;
- Subject(s) taught by the teacher;
- Classes and schedule;

Academic achievements table:

- AchievementID (unique achievement identifier);
- StudentID (link to the "Students" table);
- Description of the achievement;
- Date of receipt;
- Level of importance;

Table "Finance":

- FinancialID (unique identifier of the financial record);
- Department;
- Budget;
- Expenses for educational programs;
- Scholarships;
- Other financial aspects;

Table "Research and Development":

- ResearchID (unique research identifier);
- Faculty;
- Projects;
- Publications;
- Reports;

Table "Events and Community Events":

- EventID (unique event identifier);
- Title;
- Date;
- Participants (students, teachers);

- Results;

Table "External Relations":

- PartnerID (unique partner identifier);
- Company/Organization;
- Type of partnership (e.g., internships, joint projects);
- Contact information.

Creating a system for collecting information for educational activities of universities may include the creation of an information server or data collection system that will help universities to effectively manage and analyze various data. The main components to consider when developing a system for collecting information are the target audience, data types, process automation, user interface, data security, etc.

Open data on scientists and their scientific publications are usually available in unstructured or poorly structured formats. It needs construction and primary processing before it can be stored and used. Once the information is structured, it is stored in a database. The system can run on a single server or be split into several different servers to optimize usage. If the components of your system are located on different servers, you must provide communication between the components via a local area network or the global Internet. Each component has its own API for exchanging tasks and results of their execution between services, regardless of their physical location.

The visualization module allows you to interact with the user. Its architecture is typical for modern web applications. It consists of several programs written in Python using the Django framework and running on the Nginx web server. As a result, users receive HTML documents from the server on demand. The Bootstrap, jQuery, and Highcharts frameworks were used to stylize the display of elements. Virtual environments are used to isolate packages on the server and avoid version conflicts. The Supervisor program monitors the performance of the modules. If a process is urgently terminated, it is automatically restarted. All

information is stored in a relational database. This database is physically implemented in the Postgress database, but the database is managed by interacting with Django ORM.

ORM is a programming technology that combines the concepts of databases and object-oriented programming languages to create a "virtual object database". This approach allows you to abstract from the physical implementation of the database and simply move it to another server.

The main models in the database are:

1. User (contains a username, password, e-mail address, and information about his/her rights).
2. Scientist (contains information about the scientist: surname, name, patronymic in Ukrainian, Russian and English, academic titles and degrees, information about the place of work by referring to the relevant models, establishing links to the user's publications and reviews of his or her scientific activities).
3. Publication (contains information about the publication: title, source, link to the file, connection with the author and other publications by citation).
4. Citation (identifies the relationship between publications, as well as additional information about the source of citation information).
5. University (information about the university: name, type, contact information, information about the departments and communication with users to identify the responsible person (administrator)).
6. Structural subdivision of the university (faculty or institute, communication between universities and researchers for the implementation of the cascade).
7. Assessment of the competitiveness of the university's educational activities (the assessment includes scientific and commercial indicators identified for the relevant facility and the date of its opening).

The peculiarity of databases is that every time the results of scientific activity are evaluated, the results are saved in the database. The system displays the last found rating value for the user. If a certain period of time (for example, 1 day) has passed since the search for ratings, a request for an update will be made at the same time, and you can also refer to the history of the search for ratings. Important parts of the functionality that require a large amount of computation and database access are moved to the calculation module. These functions include, but are not limited to, calculating research performance scores, searching databases and adding new information to citations and publications, determining the direction of research, and sending out Masu emails. Celery servers are used to manage background computing tasks. Two queues are implemented on the server, containing tasks with different priorities. Using two queues, you can reduce the delay in responding to user requests. By managing the results of calculations, you can also reduce the computational load on the server. For example, if the results of a user's survey were calculated less than a day ago, the last result found is returned to the user and no new calculations are performed.

This module consists of spiders for scraping information from the international scientometric databases Scopus and Google Scholar. The spiders are written using the Scrapy framework and run on the Scrapyd virtual server. Scrapyd capabilities are used to manage information collection tasks. The system's APIs are used to save the results. New spiders can also be written for the module to expand its capabilities.

#### **Conclusions to chapter 4**

1. The article describes a program module for assessing the competitiveness of educational activities of universities, in particular modules for collecting information about the activities of the university in order to assess its competitiveness, a structural model for implementing a system for assessing the competitiveness of educational activities of universities using Web technologies, technology for implementing a Web resource for

filling the database with parameters of the university's information environment to assess the competitiveness of its educational activities.

2. The method of calculating competitiveness on the example of five universities is described: Beijing University (Beij. Un.), Shanghai University (Shan. Un.), Nanjing University (Nank. Un.), Wuhan University (Wuh. Un.), Harbin Institute of Technology (Har. Un.). To verify the developed methods and models, a database with information on 311700 scientific publications authored by 77898 Chinese scientists affiliated with these universities was collected. The scientific publications were categorized based on the topics covered in these publications. An evaluation scale and 15 criteria were proposed, each with additional sub-criteria. The results show that the proposed method of evaluation is close to the results of the QS ranking, with only one difference. This is due to the fact that the QS rating also takes into account other parameters that could not be obtained from open sources in this study.

## CONCLUSIONS

The development of the state, the emergence of new innovations and ideas are not least ensured by the effective operation of universities. Now, in the context of digital transformation, there are many factors that influence this activity. A large number of parameters are difficult to measure, they have different types of data, and it is also difficult to understand which of the parameters of the university's activities are important for its competitiveness. The changes that are taking place in the education system of most countries, especially with the onset of the COVID-19 pandemic, have significantly changed the field on which to base university competitiveness assessments. Classical evaluation approaches do not take into account all aspects of educational activities and do not take into account the dynamics of transformation of the university's information educational environment.

Thus, this dissertation solves an important task, namely: the development of methods and models for assessing the competitiveness of educational activities of universities in the context of digital transformation, taking into account the dynamics of the information university environment (scientific component). Also, the important task of automating the assessment of the competitiveness of educational activities of universities based on the use of web technologies is being solved (practical component). The main provisions and results of the research have been implemented and applied in the activities of Yancheng Politecnic College.

The following results were obtained in this paper:

1. The peculiarities of using system-dynamic modeling of educational activities of universities are described, the key aspects that influence the positive dynamics of university development from the point of view of system dynamics are identified. It is indicated that the use and improvement of project management methodology in the application to the educational activities of universities is the key to their progressive development and

competitiveness, especially in the context of the digital transformation that the education system is currently experiencing. An analysis of the current provisions in the management of university educational projects was carried out. It was found that the current practice of determining the quality of educational activities of educational institutions is usually focused on assessing student performance in learning. However, for a full and comprehensive assessment of the competitiveness of universities, all the components that affect this activity are important. Especially the need for their comprehensive study is manifested in the context of digital transformation. Accordingly, the relevance of developing methods and models for assessing the competitiveness of universities is confirmed.

2. It is shown that assessing the competitiveness of universities is a complex and multidimensional process that includes an analysis of various aspects of the activities of educational institutions. The main methods and criteria for assessing the competitiveness of universities are indicated, including the calculation of academic indicators, indicators of the quality of the educational process, university research and international activities, assessment of university infrastructure and resources, as well as the effectiveness of management and reporting in general. A review of these indicators is necessary for further calculations and development of methods for assessing the competitiveness of universities. It is determined that the educational activity of the university is a complex of both the educational component (quality of teaching and teaching materials, etc.) and the research component (publication activity, project and research activity). The section describes a multiple model for presenting data on the educational activities of universities in terms of the publication activity of research and teaching staff. A data presentation scheme has been formed: university, university employee, university events, etc. The described model takes into account and formalizes aspects of the university's educational activity, which is the

basis for calculating competitiveness assessments and is characterized by a systematic approach to building dependencies and relationships necessary for calculating the parameters.

3. The method of calculating the competitiveness of the university, which is calculated by the number of criteria that the university meets, is built. The criteria are formed in accordance with the requirements of the Ministry and are intended for accreditation of the university as an educational structure as a whole, but the list and value of the criteria can be set by the organization that evaluates the educational activities of the university. The formulas for calculating the university's competitiveness in the dynamics, defined as the ratio of the number of criteria that received a positive assessment to the number of criteria that received a negative assessment  $p$  periods ago, have been established. The scale of comparison of universities by the level of competitiveness is built and described. The system of parameters that determine the competitiveness of universities is built and the method of data coverage analysis is described, which can be used for a preliminary assessment of the competitiveness of the university and is based on the built parameters. The work describes the formation of the university information environment as a process of creating and maintaining a system of access to information that helps students, teachers, researchers and staff to obtain the necessary data for study, training, research and administration. University information environments, as well as information environments of university staff and teachers, contain information about educational activities. In particular, the information environment of a teacher has information about scientific publications published by the teacher, disciplines taught by the teacher, advanced training courses, assessment of scientific potential, and participation in international educational and scientific projects. The university information environment includes information about the student

population, assessment of the university's academic staff, resource support, etc.

4. The work describes a method for assessing the competitiveness of universities' educational activities, including their information environment. The method is based on the values of the identifiers of the information environment of the university and teachers. A comprehensive assessment allows to identify those areas of the university's educational activities that should be improved. The method of forecasting the competitiveness of educational activities of universities, which takes into account the dynamics of changes in the indicators of the university information environment, is described. Recommendations for the application of methods for predicting the competitiveness of university educational activities are also formed. The method of calculating competitiveness on the example of five universities is described: Beijing University (Beij. Un.), Shanghai University (Shan. Un.), Nanjing University (Nank. Un.), Wuhan University (Wuh. Un.), Harbin Institute of Technology (Har. Un.). To verify the developed methods and models, a database with information on 311700 scientific publications authored by 77898 Chinese scientists affiliated with these universities was collected. The scientific publications were categorized based on the topics covered in these publications. An evaluation scale and 15 criteria were proposed, each with additional sub-criteria. The results show that the proposed method of evaluation is close to the results of the QS ranking, with only one difference. This is due to the fact that the QS rating also takes into account other parameters that could not be obtained from open sources in this study.
5. The program module for assessing the competitiveness of educational activities of universities, in particular modules for collecting information about the activities of the university in order to assess its competitiveness, the structural model of the implementation of the system for assessing the

competitiveness of educational activities of universities using Web technologies, the technology of implementing a Web resource for filling the database with parameters of the information environment of the university to assess the competitiveness of its educational activities are described.

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## APPENDIX A. ACT OF IMPLEMENTATION



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### ACT OF IMPLEMENTATION

The act of implementing the results of the dissertation work of PhD student Chen Jie  
**«MODELS AND METHODS FOR ASSESSING THE COMPETITIVENESS  
OF UNIVERSITIES' EDUCATIONAL ACTIVITIES IN THE CONTEXT OF  
DIGITAL TRANSFORMATION»**

While writing his dissertation, Chen Jie fruitfully cooperated with our company and implemented research results for several years:

1. Evaluation of the competitiveness of universities is a complex and multidimensional process, which includes the analysis of various aspects of the activity of educational institutions, including the calculation of academic indicators, indicators of the quality of the educational process, scientific research activities of the university and international activities, evaluation of the university infrastructure and resources, as well as efficiency of management and reporting in general. These parameters have been analyzed and provided for operation.

2. In his dissertation, Chen Jie built a method for calculating the university's competitiveness, which is calculated based on the number of criteria that the university satisfies. The requirements of the ministry form the criteria. They are intended for the university's accreditation as an educational structure. Still, the list and meaning of the criteria can be set by the organization that evaluates the university's educational activities.

3. The peculiarity of the described method is that on its basis, it is possible to evaluate competitiveness in dynamics and compare universities among themselves. A scale of comparison of universities by level of competitiveness was built and described. A system of parameters that determine the competitiveness of universities has been built. This is very important for our company, as the involvement of universities in project activities is an essential component of our work.

4. Having information about the competitiveness of universities makes it possible to establish close project ties with them, which contributes to the development of the state.

We believe that the practical implementation of Chen Jie research work in the practice of enterprise activity is an important reason to believe that Chen Jie deserves to be awarded the scientific degree of Doctor of Philosophy in specialty 122 - "Computer Science".



Yancheng Polytechnic College  
Vice-chancellor **WANG SHUDONG**  
10 August 2023

**APPENDIX B. LIST OF THE APPLICANT'S PUBLICATIONS ON THE  
THEME OF THE DISSERTATION AND INFORMATION ON THE  
APPROVAL OF THE RESULTS OF THE DISSERTATION**

**Articles in professional publications of Ukraine  
(included in the list of the Ministry of Education and Science of  
Ukraine)**

1. **Chen, Jie.** (2019). Simulation modelling of competitiveness of Ukrainian higher educational institution in Zhejiang educational market. Management of Development of Complex Systems, 37, 105 – 110, dx.doi.org\10.6084/m9.figshare.9783110. [category «B»]  
<https://urss.knuba.edu.ua/files/zbirnyk-37/18.pdf>
2. **Chen, Jie.** (2019). Development of the model of the mutual influence of the factors of competitiveness of the university in the Yanchen cluster. Management of Development of Complex Systems, 38, 117 – 124, dx.doi.org\10.6084/m9.figshare.9788570. [category «B»]  
[https://urss.knuba.edu.ua/files/zbirnyk-38/20\\_0.pdf](https://urss.knuba.edu.ua/files/zbirnyk-38/20_0.pdf)
3. **Chen, Jie.** (2020). Comparison of the competitiveness of the international educational programs of Weihai Vocational College and Shanghai Transport University. Management of Development of Complex Systems, 41,141–146, dx.doi.org\10.32347/2412-9933.2020.41.141-146 [category «B»]  
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## Articles in professional publications of Ukraine

(not included in the list of the Ministry of Education and Science of Ukraine)

1. **Chen, Jie.** (2020). Development of a model of mutual influence of university competitiveness factors in the Yancheng Cluster. *Science Journal Innovation Technologies Transfer*. 40-347. <http://www.iamsti.org.ua/sjitt-2020-4-09/>

## Approbation works

1. **Chen, Jie, Ryzhkov, O.** (2021). Calculation of the competitiveness factors of international educational programs of Shanghai Transport University and Weihai Vocational College. *2021 IEEE International Conference on Smart Information Systems and Technologies (SIST)*, Nur-Sultan, Kazakhstan, 2021, pp. 1-5, doi: 10.1109/SIST50301.2021.9465969. [**Scopus, Web of Science**]

2. **Jie Chen.** (2018). Project management for education in accordance with globalization process. *V international scientific and practical conference "Information technologies and interactions"*, 57-58.

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4. **Chen, Jie.** (2019). Modelling of foreign university in chinese educational market. *I international scientific-practical conference, IMTSK-2019 (Information Modeling Technologies, Systems and Complexes)*, 2019, 113-114.

5. **Chen, Jie.** (2020). Competitiveness modeling of foreign university in Zhejiang educational market. *Seventh international scientific-practical conference «Management of the development of technologies» Topic: "Information technology development of educational content» Kyiv, 25 – 26 March 2020*, 12-13.