# Determining the Smart University Infrastructure Development Level Based on Data Models

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**Abstract.** The paper presents applied research in the framework of solving determining the smart university infrastructure development level problem. Today, all digital transformation and transition to the digital economy concept and smart society development issues are very important. Education is the intellectual core of the digital transformation, the knowledge base, and the training center for the digital economy. Therefore, more attention should be paid to the creation and development of the smart university infrastructure. The purpose of the study is to develop criteria and models for determining the level of smart university infrastructure development. To describe the management of infrastructure level assessment, we propose to use adapted mathematical methods, structural analysis, and mathematical statistics methods. The study examines trends in the development of smart education, highlights the main elements of the smart university infrastructure (technological and organizational), and examines approaches to determining the level of its development based on data models. Taking into account the diversity and volume of quantitative and qualitative indicators of the smart university infrastructure, we propose to measure the level of the infrastructure using data models and Educational Data Mining tools. Universities can use got models when forming a development strategy or selecting funding directions, to reduce the time of digital transformation and transition to the optimal state of a smart university, to prepare for accreditation or to align the smart infrastructure of individual departments.

## 1 Introduction

Among the current global development trends, the widespread digitalization of all spheres and industries with the accumulation, processing, and management of knowledge is particularly highlighted [1]. Education is the main source of development of the digital economy and a supplier of specialists who possess algorithms and tools for processing, analyzing, creating digital data and processing it, and applying smart technologies [2]. Also, effective performance in the digital economy and implementation in a smart society implies an aim need for lifelong learning any time and place.

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The main purpose of this study is to analyze the directions, methods, and results of evaluating and determining the smart university infrastructure development level and its readiness to use smart technologies [3]. This study analyzed the activities of universities but did not consider other educational levels and types.

To move on to the concept of smart university infrastructure, we will define the concept of "smart education". The formation and popularization of the smart education paradigm is evidenced by the appearance of regular conferences about smart education. Based on the V. L. Uskov, N. V. Dneprovskaya and other researchers publications [4, 5], we can conclude that smart education is a new educational system that is based on the use of smart digital technologies that allow interaction with the environment and get the knowledge, skills, and competencies of students. Smart education involves the adaptive implementation of the educational process, it is aimed at ensuring the possibility of using the advantages of digital globalization to meet the educational needs and interests of students [6].

A smart university is an element of the educational environment of smart education, a kind of smart platform or infrastructure that ensures the introduction, use, and development of smart technologies in education [7].

According to official prediction, digital education is one of the fastest-growing segments of the global education market, with an average annual growth rate of 23% since 2012. However, in the total volume of educational services, the share of digital education is only 3%, while 50% of this market belongs to the United States [8].

Russia's potential in digital education is very high, as evidenced by the growth rate of over 25%. We can also add factors such as a large geographical area, about 73.41% of the population have access to the Internet, and the market for cloud services is growing (by 40% per year) [8].

Thus, digital technologies are becoming more popular and more accessible, and leading universities are creating a smart infrastructure based on them for the development of smart education.

## 2 Analysis and Selection of Methods for Determining the Smart University Infrastructure Development Level

To select the best methods for determining the smart university infrastructure development level, we considered the main methods and approaches that are used in educational organizations. The main approaches to assessing the readiness of universities for the digital economy and the use of smart technologies in Russia are based on the methodology proposed by the World Bank [9]. This methodology has been adapted to Russian conditions. To assess the university's readiness to work in the digital economy and the development of its information infrastructure, five groups of indicators were identified in the following areas:

- information technologies application in the educational process;
- training teachers to use information technologies in education;
- management processes informatization in education;
- education information infrastructure;
- legal and regulatory support for education digitalization.

The standard application and use of information technologies for building a smart university are not enough, so using this methodology, we can only assess the implementation of information technologies in the processes of universities and assess the quantitative side of the information infrastructure.

Currently, the "Modern Educational Environment" project is being implemented in Russia as part of the State program "Development of Education". One of the main goals of the program is to develop digital educational space and increase the number of students who have completed online courses to 11 million people by the end of 2025. The following development areas are evaluated:

- improving the legal regulation of online learning;
- providing expertise in educational platforms and online courses;
- creating a digital infrastructure for online learning;
- creation of regional centers of digital competence and training of teachers and specialists in the online education field.

It is important to note that about 60% of all university expenses for the development of digital infrastructure are spent on technical elements of the digital infrastructure. At the same time, the percentage of expenses for training and development of employees in digital technologies, including those related to smart education, does not exceed even 0.5% [10]. All this affects the quality development of the information infrastructure, as university teachers and managers are carriers of knowledge and their guides in the educational process and management. Accordingly, the low efficiency of using the digital infrastructure tools of universities significantly hinders the development of smart infrastructure and smart education in general.

Taking into account the heterogeneity and volume of quantitative and qualitative indicators of the smart university infrastructure, we propose to measure the level of infrastructure using data models (network, hierarchical, ER-models) and Educational Data Mining tools.

The ER diagram at the highest level contains a description of the subject area with a description of infrastructure elements, at the next level - information objects (entities), at the lower level - reference books that provide filling of entities with normative values.

You can use Educational Data Mining tools such as classification, clustering, neural networks, trees, and regression models to analyze these models.

To describe the infrastructure level assessment management, we suggest using the mathematical methods of structural analysis and mathematical statistics.

## 3 Smart University Infrastructure Development Level Evaluation

### 3.1 Smart University Infrastructure Elements Definition

Based on the digitalization and smart education development trends, and research by a lot of scientists [11, 12, 13], we can distinguish two main elements of the smart university infrastructure: technological and organizational.

Let's look at the elements in more detail. The technological element of the smart university infrastructure includes information smart technologies used in smart education, which distinguish smart education from traditional and simple e-education.

These are information or digital technologies of the smart university infrastructure that have such properties as interactivity, data mining capability, data personalization, and more. Technologies do not depend on the platform and user localization, change the quality of content, speeding up its exchange, allow increasing the number of links, and are based on flexible standards.

The organizational element of smart university infrastructure is the effective use of smart technologies. When forming an educational program at the university, you must take into account the individual educational trajectory of each student, which requires the use of educational Data Mining technologies, and the possibility of integrating various educational programs. Educational programs must comply with the principle of continuing education. There should also be integration between educational programs within the same training area and the possibility of integrating practical courses into a common system. Legal regulations should provide all this. It is necessary to organize the management of university knowledge so that students can study current material and maintain the digital competence of teachers.

The main principles of building a smart university infrastructure are a combination of mobility, accessibility, manageability, and technology.

Thus, having defined the elements of the smart university infrastructure, we can proceed to the consideration of approaches to determining the level of its development.

### 3.2 Quantitative and Qualitative Assessment of the Smart University Infrastructure

Current approaches to determining the smart university infrastructure development level, for example, based on the recommendations of the World Bank, are most often based on a system of quantitative indicators that reflect the university's availability of information and communication tools and software products [14, 15]. This information is not sufficient to fully assess the level of the smart university infrastructure and to further develop the university's development strategy, since it only characterizes the quantitative saturation of the infrastructure with technologies, without reflecting the qualitative characteristics and efficiency of the use of technologies. It is also necessary to assess the quality of the smart infrastructure, covering all its components.

Based on the well-known classification of Romero C. and Ventura S. [16] in tools and methods of Educational Data Mining, we show the extent to which these tools are currently used in practice in Samara universities (the author 's study based on open-source data for the 2018-2019 academic year). The figure shows the percentage of usage of a certain smart infrastructure functionality (see fig. 1).

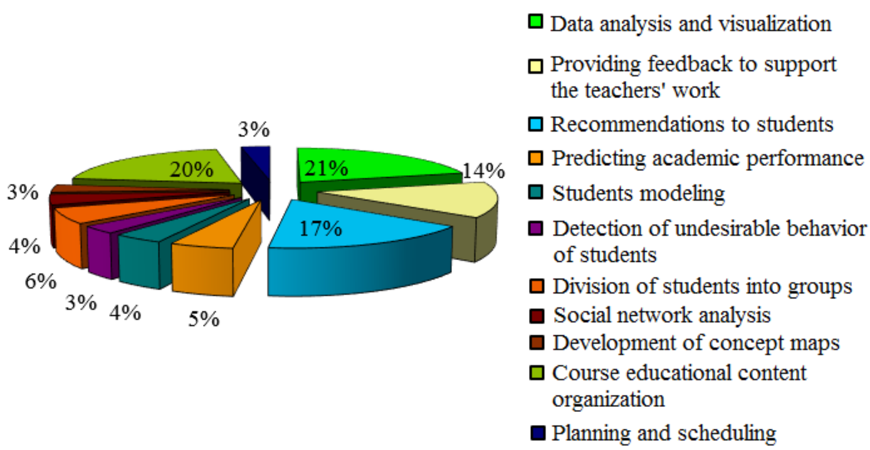


**Fig. 1.** The smart university infrastructure element development level assessment.

As we can see, smart technologies for developing concept maps and detecting undesirable behavior of students are practically not used, which confirms the underdevelopment of the organizational elements of the smart university infrastructure.

### 3.3 Tools for Evaluating Smart University Infrastructure Development

Let's look at the tools that can assess the development of the qualitative and quantitative aspects of the smart university infrastructure elements.

We propose to use the developed hierarchical data model of a set of indicators that assess the level of development of the smart university infrastructure in terms of elements (see fig. 2). You may not limit the number of elements to two, as suggested above [20]. Then there is a division into qualitative and quantitative indicators.

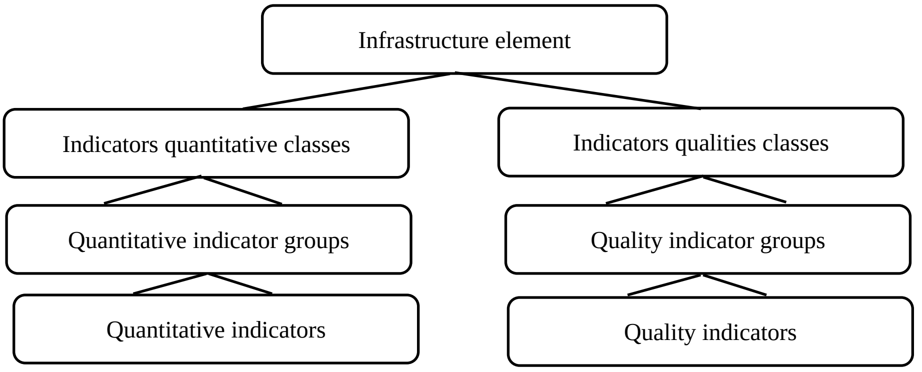


**Fig. 2.** A hierarchical model of indicators.

It is recommended to store indicator sets, for this purpose, an ER-model was developed for structuring and storing a set of indicators for assessing the level of development of the smart university infrastructure (see fig. 3).

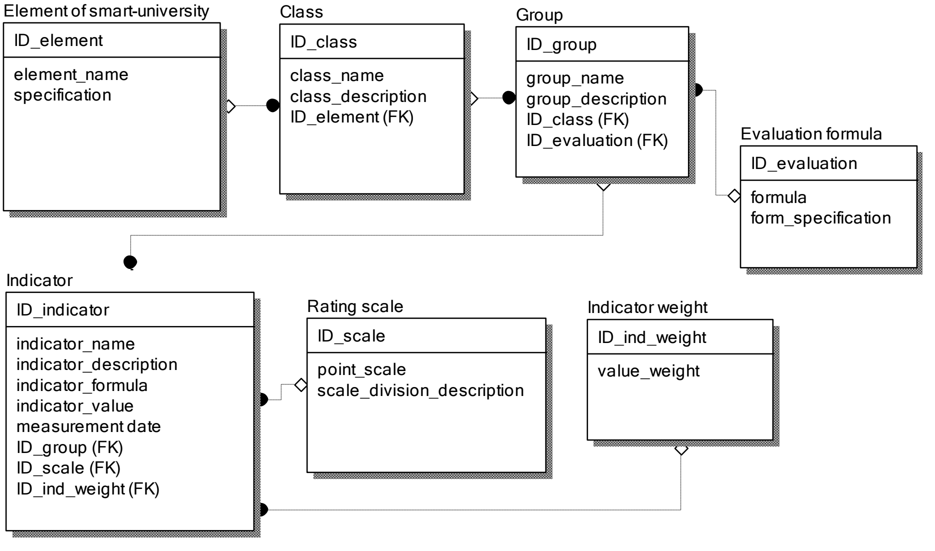


**Fig. 3.** ER-model for assessing the smart university infrastructure development level.

To process these indicators, we developed a mathematical model for assessing the level of development of the university's smart infrastructure. You can use EDM tools such as classification, clustering, neural networks, trees, and regression models to analyze these models. We recommend using software tools for data analysis, such as RapidMiner, R, Weka, KEEL (Knowledge Extraction based on Evolutionary Learning), and SNAPP. These packages include algorithms that implement data analysis methods and provide import and support for pre-processing data for use within these methods [17, 18, 19]. They also support the statistical validation of model adequacy and data visualization. Some of these packages are distributed in open source, which allows researchers to develop modules that extend the basic capabilities of the package. The tool for statistical analysis of R data currently has about 10,000 extension packages. These include interfaces to other popular data analysis packages. In turn, Weka and Rapid Miner have extensions that allow you to use the capabilities of R. The code openness of platforms such as R and Weka makes it possible to study in detail the methods and algorithms used by other researchers.

### 3.4 The Mathematical Methods Development for Managing Smart University Infrastructure Development

To describe the management of assessing the level of infrastructure development, we use the mathematical methods of structural analysis and mathematical statistics [21, 22].

Let the information infrastructure of a smart university in general form ($S_{INF}$) comprise a set of components ($S_i$, i = 1, 2, ... k). Each of the components, which, depends on the components of lower subordination in the hierarchy of emerging relationships.

Formalized this structural relationship can be described by the following set of dependencies.

The general mapping of an infrastructure comprising k-components of its functionally related components can be described (1)

$$S_{INF} = F(S_1, S_2, ...S_k) \tag{1}$$

Where each of the k-functionally dependent substructures is a dependency on subfunctions at a lower level of the hierarchy (2)

$$S_i = F(s_{ij}), i = 1...k, j = 1...n \tag{2}$$

Note that the level of implementation of each of the subfunctions $S_{ij}$ depends on some indicators (3)

$$s_{ij} = F(p_{ijm}) \tag{3}$$

Let's choose the additive convolution method for simplicity of calculations and get the $q$ level of implementation of subfunctions $s_{ij}$ of the smart division infrastructure according to the equation (4)

$$q = \frac{\sum_{\substack{i=1 \\ j=1 \\ m=1}}^{\substack{r \\ n \\ k}} p_{ijm}}{r} \tag{4}$$

Let's reduce got expression to the level of implementation of the basic functions of the smart infrastructure, taking into account the weight coefficients of the influence of each component on the overall development of the smart infrastructure, we get (5)

$$S = \frac{\sum_{\substack{i=1 \\ j=1}}^{\substack{n \\ k}} (\beta_{ij} \times s_{ij})}{n} \tag{5}$$

Then you can estimate the level of development of the entire infrastructure as (6)

$$S_{INF} = \frac{\sum_{\substack{i=1 \\ j=1}}^{\substack{n \\ k}} (\alpha_i \times s_{ij})}{k} \tag{6}$$

As a result, we get a mathematical model for assessing the smart university infrastructure development level. We determined weight coefficients by expert methods [23].

It is recommended to use the scale presented in table 1 to evaluate the indicator that provides recommendations for the development of infrastructure.

**Table 1.** Rating scale.

| Values range | Development level |
|---|---|
| $0 \leq q \leq 0{,}5$ | Low |
| $0{,}51 \leq q \leq 0{,}75$ | Acceptable |
| $0{,}76 \leq q \leq 1$ | High |

Based on the developed models, we assessed the smart university infrastructure development level on the example of leading universities in the Samara region. The got data showed that the level of development in 90% of cases is acceptable, which shows the readiness of universities to build a smart educational space and to transform based on digital technologies.

## 4 Conclusion

For a full assessment of the smart university infrastructure level and further building of the university development strategy, there is not always enough information that characterizes the quantitative saturation of the infrastructure with technologies, without reflecting the quality characteristics and efficiency of the use of technologies.

It is recommended to take into account the heterogeneity and volume of quantitative and qualitative indicators for measuring the infrastructure level, which can be conducted using data models, mathematical tools, and Educational Data Mining tools.

Universities can use got data when forming a development strategy or selecting funding directions, for preparing for accreditation or leveling the smart infrastructure of individual departments.

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