

PAPER

Setting Up and Implementing ArcGIS to Work with Maps and Geospatial Data with Python for Teaching Geoinformation Systems in Higher Education

Nursuale Karelkhan¹,
Aknur Kadirbek¹(✉),
Peter Schmidt²

¹L.N. Gumilyov Eurasian
National University, Astana,
Kazakhstan

²University of Economics in
Bratislava, Bratislava, Slovakia

kadirbek_a@enu.kz

ABSTRACT

Geoinformation systems, as teaching tools in education, are closely linked to interdisciplinary and natural sciences. Currently, the application of geoinformation systems (GIS) in the educational process holds great potential for higher education. This paper presents a pedagogical system for teaching and learning a GIS course, along with a wide range of information sources that educators can choose from. The pedagogical system of introducing special GIS courses is divided into content, organizational and methodological structures. The theoretical and practical foundations of the introduction of special GIS courses are also considered. Additionally, the paper provides information about practical works setting up and implementing ArcGIS to work with maps and geospatial data with Python. The pedagogical system described in this paper was employed in the educational process of the L.N. Gumilyov Eurasian National University (Astana, Kazakhstan) and K. Zhubanov Aktobe Regional University (Aktobe, Kazakhstan). This experimental research examines how perceptions of geocapabilities evolved among 119 higher education students as they acquired technical skills in web mapping by investigating real-world issues with ArcGIS.

KEYWORDS

geoinformation systems, higher education, ArcGIS, Python

1 INTRODUCTION

The global market value of geographic information system (GIS) is projected to reach \$24,607.7 million by 2030, compared to \$8,185.9 million in 2020, reflecting an 11.6% compound annual growth rate (CAGR) between 2020 and 2030. As this technology makes it possible to visualize, analyze, and interpret geographical information to ascertain trends, patterns and relationships, investments in this field are on the rise [1].

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GIS is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can use any information that includes location. The location can be expressed in many different ways, such as latitude and longitude, address, or ZIP code [2].

In educational setting, GIS helps students to understand content across multiple disciplines, extending beyond geography to subjects such as history, mathematics, language arts, environmental studies, chemistry, biology, civics, and many others [3].

GIS has revolutionized the methods and scope of spatial analysis resulting in a dramatic change in the field of Geography. Moreover, it has become a major component in various other disciplines that involve spatial components, including biology, political science, urban planning, geology, sociology, and more. Furthermore, GIS has also instigated substantial reforms in geographic education [4].

A growing number of educators worldwide have come to recognize the vital role of geotechnologies, which encompasses GIS, global positioning systems (GPS), and remote sensing, in preparing students to become future decision-makers. The challenges posed by local, regional, and global issues in the 21st century demand individuals who possess spatial thinking abilities and who can effectively utilize geotechnologies. While some educators focus on teaching geotechnologies as a discipline, emphasizing the development of skills, others employ it as a teaching tool for subjects, such as geography, history, environmental studies, Earth Science, biology, mathematics, economics, and others [5].

It is imperative for GIS education to be established as a government policy in secondary schools and universities. Additionally, promoting and supporting different certificate programs for staff training, both in the private sector and governmental organizations, should be encouraged to increase productivity and quick decision-making [6].

In this regard, we set the following goal for the development of GIS training in higher education.

The purpose of the research: The study aims to identify the theoretical and practical foundations for the creation and implementation of GIS teaching methods in higher education. To achieve this purpose, the following **tasks** were set:

- Analysis of the experience of teaching and learning ArcGIS in higher education
- Creation of the basis of the methodology of GIS teaching, and its implementation in the educational process in higher educational institutions

The object of the study is to establish the process of teaching GIS.

The following sections present the research model proposed for teaching GIS training in higher education: literature review, research methodology, data collection and analysis, and results and conclusions.

2 LITERATURE REVIEW

Currently, numerous research papers are being published since the use of GIS in education is an urgent topic.

In the article “GIS-based virtual field trip as a tool for remote education,” the authors evaluate the usefulness of virtual field trips as tools for preparatory activities before an actual field trip that takes place in the same area and justify their contribution to providing a better understanding of geomorphological processes and landscape evolution [7].

In the paper “Understanding higher education students’ developing perceptions of geocapabilities through the creation of story maps with geographical information systems,” the authors observed shifts in undergraduates’ conceptions of geocapabilities as they learned ArcGIS StoryMaps by researching and producing story maps about real-world issues through flipped classrooms. Students can develop insights into different geocapabilities when they learn GIS technologies through researching real-world issues. GIS teachers can use flipped classrooms to synthesize teaching and learning about GIS and teaching and learning with GIS [8].

With the increasing popularity of global online mapping web applications (e.g., Google Maps, Microsoft Virtual Earth, Yahoo Maps, ArcGIS Online), Web GIS has become an integral part of “business exchange” and has created great opportunities for e-Learning. Three case studies based on ArcGIS Online has been analyzed in the paper “Geographical information science and technology-based STEM education in e-Learning” to conceptually confirm the relationship between GIS/T and eight NGSS science and engineering practices, to illustrate added values of GIS/T in science, technology, engineering, and mathematics (STEM) education, and to exemplify immense contributions of GIS/T to e-Learning [9].

The paper “Teaching innovation in stem education using an unmanned aerial vehicle (UAV)” provides educators vital recommendations for designing UAV exercises to improve access to UAV-related educational content. The use of UAVs has increased in the STEM professions [10].

The work “3D GIS Interactive Visualization of the Archaeological Sites in Qatar for Research and Learning” focuses on the development of a computerized system that aids classification, administration, and representation of archeological discoveries within a 3D web-based repository; besides enabling 3D GIS to spatially store, share, envision, and examine complex archeological components [11].

In the research article “3D Map of Dry Land Use Based Aerial Image as Learning Media in Era of Education 4.0,” the authors have observed that 3D map of dry land-based on aerial imagery with QGIS is feasible and can be used as a learning media in the subject of land resource evaluation [12].

In the Republic of Kazakhstan, the availability of educational programs in universities that offer qualified GIS education is limited to a few units [13]. Currently, only leading universities in Kazakhstan use the GIS system for educational purposes. Notably, there are also Kazakhstani scientists actively addressing GIS-related challenges, in particular Alibekova N. T., Zhusupbekov A. Zh., and Morev I. O. In addition, the textbook “An Introduction to GIS” by Ian Heywood, Sarah Cornelius, and Steve Carver has been translated from English into Kazakh and is being used in universities.

Analysis of scientific literature and internet resources shows that GIS courses are being implemented in the educational programs of the renowned universities worldwide. However, it should be considered that each educational program has its own individual characteristics.

3 METHOD

As per the next task of the study, the following steps were undertaken to develop a methodology for teaching GIS and establish the practical basis for its integration into the educational process for students in natural science education programs at universities. The course “Digital technologies by industry” has been incorporated into numerous educational programs at universities in Kazakhstan. In general, the workflow of the study is illustrated in Figure 1.

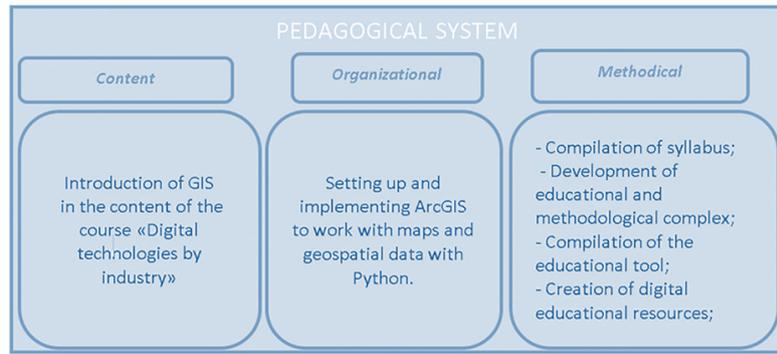


Fig. 1. Pedagogical system for teaching GIS

The effectiveness of the pedagogical system was evaluated by teaching the course “Digital technologies by industry” to students of the Faculty of Natural Sciences at L.N. Gumilev Eurasian National University, the effectiveness of this pedagogical system was determined. The experiment involved both a control and a research group, consisting of 2nd-year students from the same faculty. The syllabus of the elective course was enhanced by incorporating the features using Python for map manipulation in ArcGIS. Within this course, students in the research group were trained to use ArcGIS along with Python for working with maps and geospatial data. The study also aimed to determine the advantages and benefits of incorporating geoinformation systems into higher education.

To teach students, a textbook and digital educational resources were compiled by the authors. These materials were designed to incorporate ArcGIS into the learning process and enable the students to work with maps and geospatial data using Python. Technical and programming skills related to GIS are taught across various disciplines in higher education, with Python being the subject of focus in our case. A syllabus was developed, and an educational and methodological complex was created to support the teaching of GIS.

It is worth emphasizing the growing usage of freely distributed GIS software worldwide. The popularity of these tools is attributed not only to their cost-effectiveness and open source nature but also to the significant increase in their functionality in recent years. One notable example is QGIS, which has emerged as a strong competitor to ESRI ArcGIS in various aspects [14].

In the field of education, various software products are used for applications, including ArcGIS, MapInfo, Panorama, Neva, Erdas Imagine, Geo Media, and others. Among these, ArcGIS is the most widely used and is offered to students as a part of the educational program in Natural Sciences. In addition, an analysis was conducted to identify the top universities worldwide that employs GIS technologies. The findings of this analysis has been illustrated in Table 1.

Table 1. Programs for teaching GIS in higher education

No	Name of Higher Education	Programs for Teaching GIS
1	Massachusetts Institute of Technology [15]	ArcGIS, Background Geoprocessing 10.8; Desktop Tutorial Data 10.8; City Engine 2020;Data and Maps 2019.
2	Harvard University [16]	MAPA; ArcGIS.
3	Stanford University [17]	ArcGIS; Advanced 10.7.1; QGIS 2.18 LTS; Open Refine; Matlab.
4	University of Oxford [18]	ArcGIS Collector; ArcMap; ArcGIS; Story Maps; Web App Builder.
5	Imperial College London [19]	ArcGIS; ENVI.

In the given example, a world map is displayed in the ArcGIS system. The objective is to extract information about the Republic of Kazakhstan from the world map using the ArcPy library in Python. This can be done by writing the country names in the attribute table using either the serial number or the name of the country.

To access the information about the Republic of Kazakhstan, the country can be selected either by its serial number or by its name from the world map. Once selected, all relevant information about the Republic of Kazakhstan, including its map representation, appears as illustrated in Figure 2.

A selected sample of the code:

```
>>> import arcpy
>>> arcpy.SelectLayerByAttribute_management("countries.shp", "NEW_SELECTION", "" FID=133 """)
>>> arcpy.SelectLayerByAttribute_management("countries.shp", "NEW_SELECTION", "" SOVEREIGNT='Kazakhstan' """)
<Result 'countries'>
```

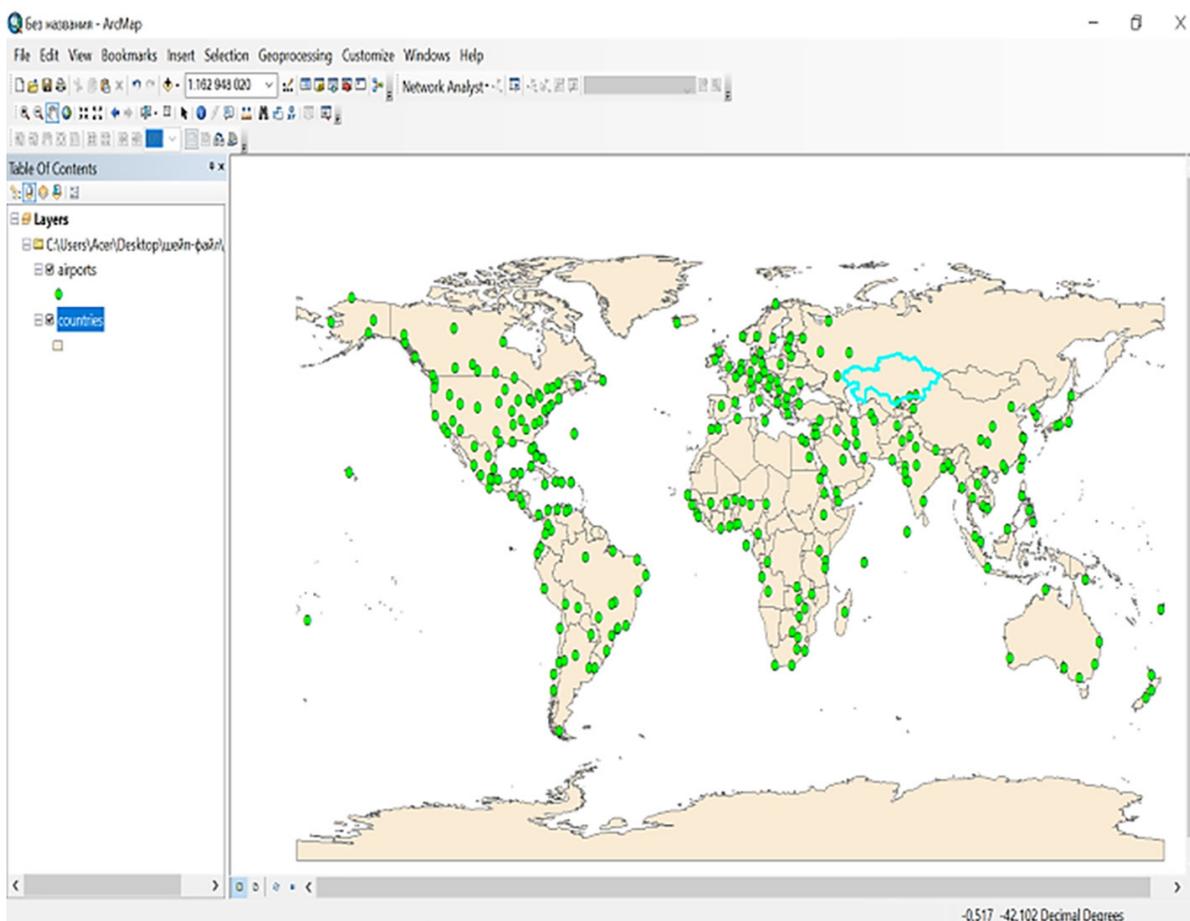


Fig. 2. A map of the Republic of Kazakhstan is chosen

The coded for Cities with airports in the Republic of Kazakhstan:

```
>>> arcpy.SelectLayerByLocation_management("countries", "INTERSECT", "airports", "0.5 Kilometers")
<Result 'countries'>
```



```
>>> arcpy.AddField_management("railways", "R", "FLOAT")
<Result 'railways'>
```

FID	Shape	osm_id	code	fclass	name	layer	bridge	tunnel	R
0	Polyline	20340738	6101	rail		0	F	F	0
1	Polyline	20341030	6101	rail	Saryagash - Arys	0	F	F	0
2	Polyline	20341339	6101	rail	Arys - Saryagash	0	F	F	0
3	Polyline	20341512	6101	rail	Arys - Saryagash	0	F	F	0
4	Polyline	22372099	6101	rail	Lugovaja - Bishkek	0	F	F	0
5	Polyline	22374721	6101	rail		1	T	F	0
6	Polyline	22376673	6101	rail		1	T	F	0
7	Polyline	22376684	6101	rail	Шымкент-Тараз (Турксиб)	0	F	F	0
8	Polyline	22376738	6101	rail	Турксиб	0	F	F	0
9	Polyline	22379123	6101	rail		0	F	T	0
10	Polyline	22379134	6101	rail	Тараз-Шымкент (Турксиб)	0	F	F	0
11	Polyline	22379264	6101	rail		1	T	F	0
12	Polyline	22379287	6101	rail		1	T	F	0
13	Polyline	22379604	6101	rail		1	T	F	0
14	Polyline	22379614	6101	rail	Тараз-Шымкент (Турксиб)	0	F	F	0
15	Polyline	22379895	6101	rail	Шымкент-Тараз	0	F	F	0
16	Polyline	22379925	6101	rail	Тараз-Шымкент (Турксиб)	0	F	F	0
17	Polyline	22380634	6101	rail	Луговая-Тараз (Турксиб)	0	F	F	0
18	Polyline	22381338	6101	rail		1	T	F	0
19	Polyline	22381359	6101	rail	Шымкент-Тараз (Турксиб)	0	F	F	0
20	Polyline	22381909	6101	rail		0	F	F	0
21	Polyline	22386026	6101	rail	Тараз-Жаңатас	0	T	F	0
22	Polyline	22386165	6101	rail	Тараз-Жаңатас	0	F	F	0
23	Polyline	22399341	6101	rail		0	F	F	0
24	Polyline	22399365	6101	rail		0	F	F	0
25	Polyline	22400964	6101	rail		0	F	F	0
26	Polyline	22401727	6101	rail		1	F	F	0
27	Polyline	22401955	6101	rail		0	F	F	0
28	Polyline	22408529	6101	rail	Тараз-Жаңатас	0	F	F	0
29	Polyline	22542214	6101	rail		0	F	F	0
30	Polyline	22553042	6101	rail		0	F	F	0
31	Polyline	22564882	6101	rail		0	F	F	0
32	Polyline	22564886	6101	rail		0	F	F	0
33	Polyline	22564915	6101	rail		0	F	F	0
34	Polyline	22565014	6101	rail	Отар-Алматы (Турксиб)	0	F	F	0
35	Polyline	22565290	6101	rail		0	F	F	0
36	Polyline	22565520	6101	rail	Турксиб	1	T	F	0
37	Polyline	22565556	6101	rail		0	F	F	0
38	Polyline	22565594	6101	rail	Отар-Алматы (Турксиб)	0	F	F	0
39	Polyline	22565597	6101	rail		0	F	F	0
40	Polyline	22565655	6101	rail		0	F	F	0
41	Polyline	22566088	6101	rail		1	T	F	0
42	Polyline	22566089	6101	rail		0	F	F	0
43	Polyline	22566090	6101	rail	Almaty1 - Almaty2	0	F	F	0
44	Polyline	22566140	6101	rail		0	F	F	0
45	Polyline	22566141	6101	rail		1	T	F	0
46	Polyline	22566153	6101	rail		0	F	F	0

Fig. 4. Example of adding a new column to a table

In conclusion, working with maps in ArcPy and utilizing the power enables the automation of essential queries and tasks. As mentioned earlier, whether working with a world map or maps of specific countries, it becomes possible to automatically retrieve or modify information about the locality within the attribute tables. Additionally, new column can be added, data can be populated, and the map can be altered accordingly.

4 RESULTS OF RESEARCH

Upon completion of GIS course, all participating students were asked to fill in a questionnaire aimed at assessing the impact of the course on their education and gathered their opinions. The survey was conducted using Google Forms, and a total of 119 students participated.

The survey consisted of questions related to various aspects, including the level of motivation, technical-technological level, and level of content quality. The results of the survey were analyzed and compared, and the findings are presented in Table 2 and Figure 5.

Table 2. Results of experiment. Components and indicators of learners' desire for ArcGis competencies

Components and Indicators	Low Level		Average Level		High Level	
	Experimental Group	Control Group	Experimental Group	Control Group	Experimental Group	Control Group
	%	%	%	%	%	%
Motivation	1.1	27.85	14	59.49	84.9	12.66
Content	1.17	35.44	56.44	51.9	42.39	12.66
Technical-technological	2.17	36.71	49.53	56.96	48.3	6.33

After the completion of the training, a questionnaire was shared among the participants. The participants in the research group confirmed that using ArcGIS had a positive impact on enhancing their spatial thinking abilities and deepening their understanding of the subject matter. The data for the study was collected using two methods: qualitative and quantitative questionnaires.

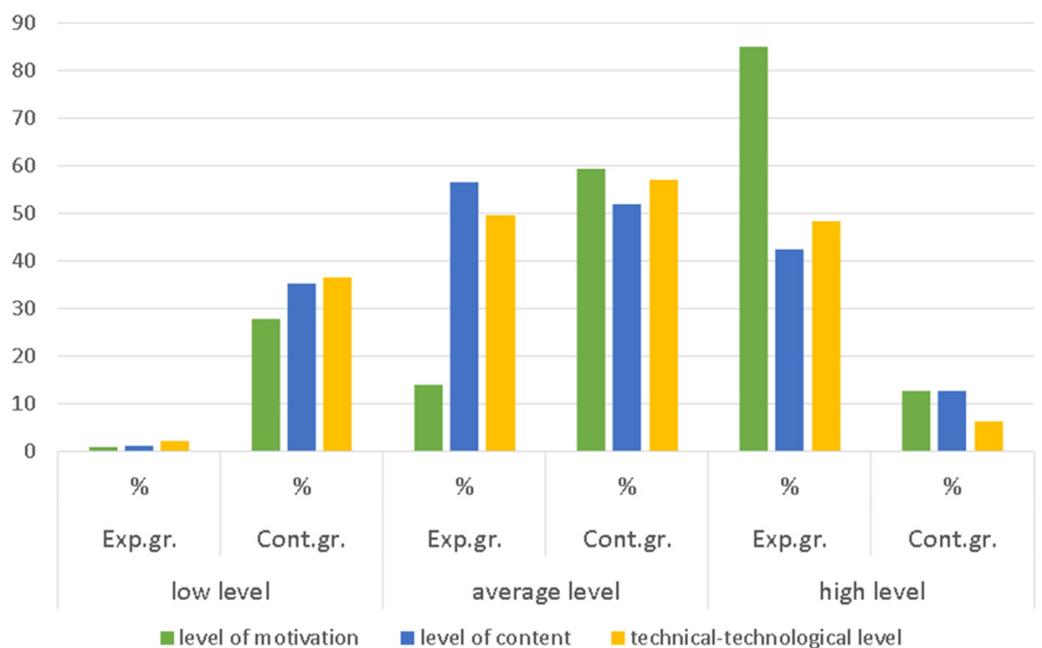


Fig. 5. Results of formative experiment

To compare the research results of pedagogical studies, non-parametric methods were used. In particular, the K. Pearson's chi-squared test was used to assess the difference between the control and experimental groups [20].

χ^2 was calculated by K. Pearson's chi-squared test (1):

$$\chi^2 = \frac{\sum |(Fe - Fb)|^2}{Fb} \quad (1)$$

where,

Fe – is the relative frequency of the data interval of the experimental group;
 Fb – is the relative frequency of the data interval of the research group.

All three values of χ^2 (level of motivation, technical-technological level, and level of content) confirmed the effectiveness of the research findings.

The effectiveness of the research results was confirmed in all three values of the tested χ^2 conditions (on interest, technical-technological and content levels). It was revealed that knowledge, skills, and abilities of the students increased by the end of the course.

The effectiveness of using the pedagogical system for teaching the course "Digital technologies by industry" in higher educational institutions and the correctness of the scientific forecast of our research work were determined by the results of the research. His study examines how 119 higher education students' perceptions of geocapabilities evolved as they learned technical skills of web mapping through investigating real-world issues with ArcGIS.

5 CONCLUSION AND RECOMMENDATION

To create and implement GIS teaching methodology in higher educational institutions, the following tasks were performed:

- 1) Analysis of GIS courses in leading countries and higher educational institutions: A comprehensive examination of the state, and practices of the GIS courses in higher educational institutions of leading countries were analyzed. This included analyzing teaching conditions in foreign countries and in Republic of Kazakhstan, as well as studying scientific literature and e-resources. The analysis revealed that there is a lack of general scientific and practical foundations for GIS training in the Republic of Kazakhstan.
- 2) Justification of the importance of using ArcGIS and Python: In order to deepen students' knowledge, and improve their skills and abilities in accordance with modern requirements, the importance of using ArcGIS software and Python programming language in the GIS creation was established. The theoretical bases of its introduction into the educational process and their practical implementation was justified.
- 3) Implementation of ArcGIS in educational institutions: The authors carried out work in setting up and implementing ArcGIS for working with maps and geospatial data in Python at L.N. Gumilyov Eurasian National University in Astana and K. Zhubanov Aktobe Regional University, in Aktobe, both located in Kazakhstan. They proposed syllabus, teaching-methodical collection, educational materials and digital educational resources that were approved for use in education. The effectiveness of the proposed pedagogical system was demonstrated through conducting an experiment and employing non-parametric methods.

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7 AUTHORS

Nursaule Karelkhan, PhD, associate professor, Department of Computer Sciences, Faculty of Computer Sciences, L.N. Gumilyov Eurasian National University, Satpayev str 2, 010000 Astana, Kazakhstan (E-mail: 801205450700@enu.kz).

Aknur Kadirbek, Doctoral student, Department of Computer Sciences, Faculty of Computer Sciences, L.N. Gumilyov Eurasian National University, Satpayev str 2, 010000 Astana, Kazakhstan (E-mail: kadirbek_a@enu.kz).

Peter Schmidt, PhD, Chief of Department of Applied Informatics, Faculty of Economic Informatics, University of Economics in Bratislava, Bratislava, Slovakia (E-mail: Peter.schmidt@euba.sk).