Higher education in the field of electrical engineering and computing through students' wishes and teachers' scientific papers

Jelica Protić, Petar Ristić, Tijana Panić Rubežić and Uroš Romić

***Abstract*—The field of electrical engineering and computing is one of the most rapidly growing fields of engineering, which has a great impact on the development of society. In this paper, we will summarize the results of a data analysis on enrolment to the University of Belgrade with special emphasis on the School of Electrical Engineering and its modules belonging to the study program Electrical Engineering and computing. First, we will observe the perception of students expressed by their simultaneous applications for enrollment at multiple schools of the University of Belgrade, to find out which schools are considered similar from their viewpoint. After that, we will observe the priority wish lists of modules that students choose after the common first year of study, when they opt for one of the six bachelor academic study modules of the curriculum in Electrical Engineering and Computing at the School of Electrical Engineering in Belgrade. Finally, the coverage of different subfields of electrical engineering and computing will be examined through the analysis of scientific papers published by the faculty members of the School of Electrical Engineering in Belgrade. Classification of scientific journals in which they publish their papers into Web of Science (WoS) categories can be considered as indication of their primary research interests, which shape the scientific and professional profile of the institution. In the conclusion of the entire analysis, we will discuss multidisciplinary orientation as a trend that is increasingly imposing itself and erasing clear boundaries between subfields of electrical and computer engineering, that were clearly defined in the past.**

***Keywords*—electrical engineering, computing, higher education, enrollment process, scientometrics, Web of Science**

I. Introduction

The parallel development of teaching and research in the field of electrical engineering and computing is caused by evolution of the society and accelerated development of the profession, whose products have become an important part of our everyday life. The classification of subfields within the field of electrical engineering and computing is caused by the historical development of the profession. There are many different classifications of subfields, which are not always compatible, and which can affect both the curriculum design in this area, selection of modules in the study programs, which are subject to the accreditation process, as well as the profiling of young researchers during their Ph.D. studies. It also affects the choice of the most appropriate journals for papers' submission, considering categorization of journals in international index databases.

In the first part of this paper, we will analyze the preferences of potential students when enrolling to the University of Belgrade [1]. Many of them simultaneously apply for enrollment at multiple schools, having in mind strong competition and enrollment uncertainty [2]. Despite the announcements that the state matriculation exam will replace entrance exams as a primary mechanism for classification of candidates who enroll to the University, it has not yet happened. According to the recent announcements of the Ministry of education from May 2023, the state matriculation exam is postponed until 2025/26, so entrance exams organized by individual schools of the University of Belgrade will be continued at least until then.

Applications to multiple study programs, i.e. faculties, will continue asynchronously, so the order of preferences of the desired options for each candidate will remain unknown before the actual enrollment. Even then, the choice depends on the ranking positions of the candidate on different lists, as well as the financial circumstances, since the candidate can be financed from the state budget or self-financed. However, it can be assumed that a potential student sees the schools to which he or she applies simultaneously as thematically similar, so it is interesting to see which schools can be grouped on this basis and examine whether they are also organizationally united in the same group at the University of Belgrade. In this analysis, our special focus is on the School of Electrical Engineering in Belgrade.

In the second part of the paper, we will consider enrollment in the second year of bachelor academic studies of the study program Electrical Engineering and Computing at the School

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of Electrical Engineering in Belgrade. When enrolling in the second year of the study program Electrical Engineering and Computing, each student expresses his preferences by specifying the order of the six divisions, i.e., accredited modules, starting with the one he prefers to enroll in [3]. In this case, we can also assume that the student perceives the modules that he lists as successive wishes as thematically close. However, students can consider other selection criteria, such as the assessment of the current demand on the labor market for certain profiles of engineers. The real closeness of the modules can be seen through the common courses that students who attend different modules take together in the higher years of study, as well as through the historical perspective of the origin of these divisions or modules.

The third part of this paper examines the fields of electrical engineering and computing through the narrower scientific fields defined by the Statute of the School of Electrical Engineering. On the other side, there is a classification of journals in which teachers at the School of Electrical Engineering have published their papers during the timespan of the last 10 years. As a data set, only papers published in journals with impact factor in Web of Science (WoS) [4] are considered, and each journal is classified in one or more of the 252 WoS categories. A comparison of dominant journal categories and their combinations provides an insight of the research interests of teachers in their scientific work.

II. Students' wishes when they apply for the enrollment to bachelor academic studies at the University of Belgrade

University of Belgrade is the biggest public university in Serbia, consisting of 31 faculties/schools and 11 institutes. It is ranked among the top 500 world universities according to the ARWU ranking, also known as "Shanghai ranking". Candidates apply separately and independently for each of the faculties/school to which they might enroll, while the data on the candidates is aggregated and the final lists are published both by the faculties/schools and on the University of Belgrade website. As there is no ranking of preferences during enrollment, we can only analyze the overlapping of applications to several faculties, from which one can see which combinations of faculties are the most popular. Possible insight into the candidate's preferences can only be gained after enrolment. Students express their perception of the 'thematic closeness' of the two schools/faculties by applying to them simultaneously. If we take the total number of candidates who simultaneously apply to the two faculties as the weight of the edge connecting the two nodes representing these faculties in a network, we can analyze it, using methods typical for social networks [5]. We can find clusters in such a network, which unite several thematically related faculties of the University of Belgrade. In this paper, we are primarily interested in the position of the School of Electrical Engineering in Belgrade, which has a study program in Electrical Engineering and Computing on the three levels, while a separate study program in Software Engineering is accredited only at the level of bachelor academic studies.

There are ten faculties in the Group of Social Sciences and Humanities:

- Faculty of Economics (EF)
- Faculty of Law (PRF)
- Faculty of Orthodox Theology (PBF)
- Teacher Education Faculty (UF)
- Faculty of Security Studies (FB)
- Faculty of Special Education and Rehabilitation (SER)
- Faculty of Political Sciences (FPN)
- Faculty of Sports and Physical Education (SFV)
- Faculty of Philosophy (FZF)
- Faculty of Philology (FLF)

There are four members in the Group of Medical Sciences:

- School of Medicine (MDF)
- Faculty of Dental Medicine (STF)
- Faculty of Veterinary Medicine (FVM)
- Faculty of Pharmacy (FF)

There are six faculties in the Group of Sciences and Mathematics:

- Faculty of Biology (BF)
- Faculty of Geography (GGF)
- Faculty of Mathematics (MTF)
- Faculty for Physical Chemistry (FFH)
- Faculty of Physics (FIF)
- Faculty of Chemistry (HF)

There are eleven faculties in the Group of Technology and Engineering Sciences:

- Faculty of Architecture (AF)
- Faculty of Civil Engineering (GF)
- School of Electrical Engineering (ETF)
- Faculty of Mechanical Engineering (MF)
- Faculty of Agriculture (PF)
- Faculty of Mining and Geology (RGF)
- Faculty of Transport and Traffic Engineering (SF)
- Technical Faculty in Bor (TFB)
- Faculty of Technology and Metallurgy (TMF)
- Faculty of Organizational Sciences (FON)
- Faculty of Forestry (ŠF)

TABLE I
THE NUMBERS OF APPLICANTS FOR THE MOST POPULAR COMBINATIONS OF FACULTIES DURING THE LAST FOUR-YEAR PERIOD

Year ->	2019	2020	2021	2022	Total
MDF + STF	417	380	389	339	1525
EF + FON	331	358	380	358	1427
ETF + FON	181	190	213	232	816
ETF + MTF	186	190	180	203	759
SF + FON	168	154	198	152	672
MTF + FON	192	176	156	136	660

The most popular combinations of faculties/schools that potential students choose to apply for enrolment are presented in Table 1. It is obvious that students very often apply simultaneously to the School of Medicine (MDF) and Faculty of Dental Medicine (STF). Faculty of Organizational Sciences (FON) appears in four popular combinations, where the combination with the Faculty of Economics (EF) is the most frequent, probably because of the business and management orientation of FON. The School of Electrical Engineering (ETF) also makes a popular combination with FON, because both institutions have study programs in computing, just like the Faculty of Mathematics (MTF) which appears in combinations with both ETF and FON. There are also some candidates who apply for enrolment to ETF, FON and MTF at the same time, and the total number of such candidates for a four-years period was 281.

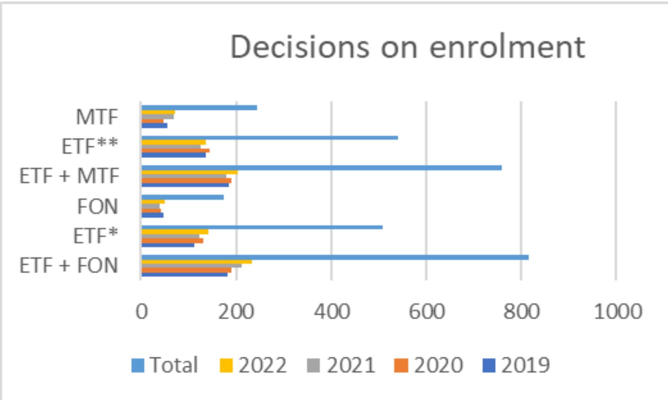

Fig. 1. Students' enrolment when they apply for two faculties/schools. After applying to ETF+MTF, ETF** students enroll to ETF, and MTF students enroll to MTF. After applying to ETF+FON, ETF* students enroll to ETF, and FON students enroll to FON.

When we consider the final decision of students who apply to two faculties/schools, and one of them is ETF, we can see in Figure 1 that the majority of them will chose ETF, as shown in Figure 1. For the ETF+FON combination, 62.3% were enrolled to ETF and 21.4% were enrolled to FON, while in the case of ETF+MTF combination, 71.1% were enrolled to ETF and 32.1% were enrolled to MTF, which makes the total over 100%. This is the case because 47 students over the timespan of four years enrolled to both ETF and MTF.

An analysis and visualization of a 'social network' [5] of schools/faculties was performed in [1], using the data about enrolment in the school year 2020/21. For each pair of schools/faculties the weight of edges is proportional to the number of students who applied for both schools. The network in Figure 2 was partitioned into 4 communes using Gephy [6]. The only isolated node is Technical Faculty in Bor (TFB), probably because of its remote geographical position. Without this node, three communes were detected, which partially correspond to the formal groups of faculties, with some interesting exceptions.

The first commune consists mostly out of the schools/faculties belonging to Social Sciences and Humanities group, presented by blue color in Figure 2.

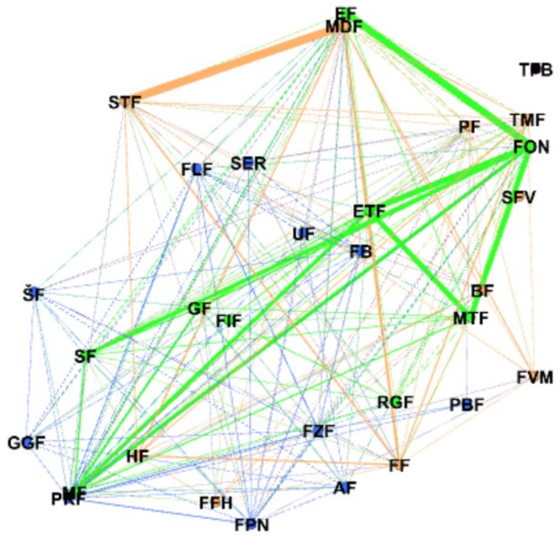

Fig. 2. Network of faculties/schools, members of the University of Belgrade. There are 31 nodes, representing faculties/schools, and the weight of an edge between two nodes depends on the number of candidates who simultaneously applied to them (generated by Gephy [6]).

The only exceptions are the Faculty of Economics (EF), grouped together with technical schools, as well as Faculty of Sports and Physical Education (SFV), grouped together with medical schools. On the other hand, this group also includes Faculty of Geography (GGF), Faculty of Architecture (AF) and Faculty of Forestry (ŠF).

The second commune consists mostly out of the schools/faculties belonging to the Group of Medical Sciences, presented by orange color in Figure 2. Six schools/faculties in this commune do not belong to this formal Group at the University: Faculty of Sports and Physical Education (SFV), Faculty of Biology (BF), Faculty of Chemistry (HF), Faculty for Physical Chemistry (FFH), Faculty of Agriculture (PF), and Faculty of Technology and Metallurgy (TMF).

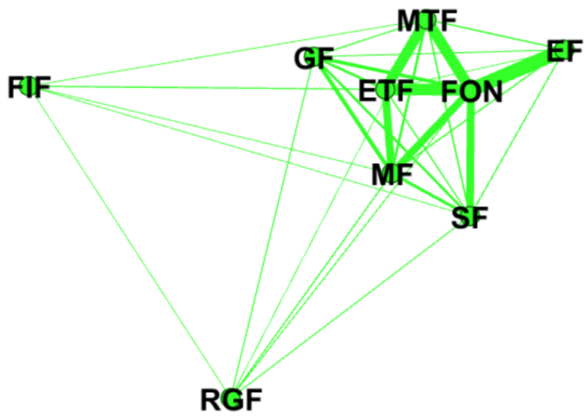

Fig. 3. Network of faculties/schools, members of the University of Belgrade, which includes ETF, FON, MTF and MF, institutions which have accredited study programs in computing (generated by Gephy [6]).

Finally, the most interesting commune for this analysis in shown in green color in Figure 2, so we present it separately in Figure 3. Strong relations between ETF, FON, MTF and MF can be observed, as well as specific relation between FON and EF, which brings Faculty of Economics (EF) into this group. Faculty of Mechanical Engineering (MF) is also an important member of this commune, due to its relations with ETF and FON. The commune also includes Faculty of Civil Engineering (GF), Faculty of Transport and Traffic Engineering (SF) and Faculty of Mining and Geology (RGF) from the Group of Technology and Engineering Sciences, as well as Faculty of Physics (FIF). We assume that all the schools/faculties in this commune share the common orientation to new technologies, mostly related to computing and/or technical management, so they are observed as more or less similar by the candidates.

III. Students' wishes when they apply for the enrollment to modules of electrical engineering and computing at ETF

University of Belgrade – School of Electrical Engineering (ETF) has two accredited study programs (curricula) of the Bachelor Academic Studies: the curriculum of Software Engineering (SI) with the enrolment of 180 students per year, and the curriculum of Electrical Engineering and Computing (ER) with the enrolment of 540 students per year. The ER curriculum has six study modules (divisions): Electronics and Digital Systems (OE), Power Engineering (OG), Computer Engineering and Informatics (IR), Signals and Systems (OS), Telecommunications and Information Technology (OT), and Physical Electronics (OF).

The first year of study has the core curriculum for all the modules, but after that, at the beginning of the second year, students select one of the study modules (divisions). The students who opt for Telecommunications and Information Technology module can later select one of tree elective sub-modules, these being: Information-Communication Technologies, Audio and Video Technologies, and Microwave Engineering. The students who opt for Physical Electronics can later choose one of two elective submodules: Nanoelectronics and Photonics or Biomedical and Ecological Engineering.

In order to keep distribution of students across modules in accordance with the capacities and resources of the divisions, but also with respect to students' wishes, School of Electrical Engineering every year determines the minimum and maximum number of students who can enroll to each module. The quotas are discussed and approved by the Commission of Bachelor Studies and the Teaching-Scientific Council.

Each student lists his or her preferences by specifying the order of the six modules, starting with the most preferred one. Students are ranked based on their success in the first year of studies, taking into account the grade and ECTS of each course, as well as the efficiency expressed by passing their exams on time and avoiding multiple enrolments into the first year of studies. Although most of the students finally enroll to the most preferred module, a significant number of students end up with the enrolment to the module expressed as a second or third wish.

Discussion on the values of minimum and maximum number of students who can enroll to each module and its comparison to the numbers of expressed wishes is out of scope of this paper, since it depends on the general mission to develop all relevant disciplines of electrical engineering and computing, as well as on the existing distribution of teaching stuff across narrow scientific disciplines. Our main focus is to examine the student' perception about the thematic closeness of modules expressed by their distance in the wish lists which they provide.

In the analysis presented in [2] 3908 wish lists of students from 9 generations were analyzed. In theory, there are 6! =720 permutations of modules that can be expressed as wish lists. However, some examples of wish orders for students who prefer certain modules were found to be more frequent than the others and those permutations are listed in Table 2.

TABLE II
WISH LISTS WITH THE HIGHEST NUMBER OF OCCURRENCES FOR EACH PREFERRED MODULE

Wish list						%
OS	IR	OE	OG	OT	OF	13%
IR	OS	OE	OT	OG	OF	10%
OT	OS	IR	OG	OE	OF	7%
OG	OS	OT	IR	OE	OF	6%
OE	IR	OG	OS	OT	OF	5%
OF	OS	OE	OG	OT	IR	1%

However, many other wish list permutations were found in the data set, some of them being more frequent than these six permutations shown in the Table 2. We have taken all 3908 wish lists from the dataset and computed distances between modules in each of them. The distance is determined by subtracting the positions of two modules in the wish list and taking its absolute value, e.g., it is one if the modules are neighbors in the wish list, and it is 5 if one module is on the top of the wish list and another is the last one. By taking an arithmetic means of all distances, we have obtained a distance matrix shown in the Table 3.

TABLE III
DISTANCE MATRIX BASED ON STUDENTS' WISHES

Module	OS	IR	OT	OG	OE	OF
OS		1.35	1.5	1.63	1.68	2.9
IR	1.35		1.4	1.76	1.46	2.53
OT	1.5	1.4		1.36	1.66	1.81
OG	1.63	1.76	1.36		1.06	1.82
OE	1.68	1.46	1.66	1.06		1.81
OF	2.9	2.53	1.81	1.82	1.81	

From Table 3 it is obvious that the distance between OG and OE has minimal value of 1.06, which means that the two appear as neighbors in many cases. With a distance of 1.35 to OS, 1.4 to OT and 1.46 to OE, IR as a typical computing discipline appears to be close to the areas from which computing originated at ETF. However, the slightly smaller distance of 1.36 between OT and OG can be regarded as a wish of students to work in big, public systems established on traditional electrical engineering. On the other side of the spectrum, OF with a predominantly scientific background is closer to OT, OG and OE, engineering disciplines that are based on the knowledge base of physics, then to the other two disciplines that require strong background in the IT subfields.

Although the results can be regarded from the point of view that considers the mandatory and elective courses that appear in the curricula of multiple modules, they can be also present because of current demand for certain profiles of experts on the labor market.

IV. Analysis of scientific papers by WoS categories

After examining the position of electrical engineering and computing through the wishes of students on the level of the University and the School of Electrical Engineering, we will concentrate on the interests of the teaching staff, which can be examined by identifying different subfields of their publications in electrical engineering and computing. Faculty members of the School of Electrical Engineering in Belgrade publish their best papers in scientific journals indexed in Web of Science (WoS), as the publication of papers in such journals with impact factor represent the main condition for promotions and applications for scientific projects. The Web of Science (WoS) categories of journals can be considered as indication of the research interests of scientists who publish their papers in those journals. The combination of such WoS categories shapes the scientific profile of the institution.

Source of data for analysis of scientific papers can be local or institutional [7], such as an information system of a higher education institution, like the one maintained by the School of Electrical Engineering in Belgrade, where the employees can input their data and see it published on the Web site the next day, directly from the database. Another source of data can be the international indexed database, where one can specify the queries and export data about published papers.

As stated in our previous paper [7], the results of the two methods of data extraction can differ, because some retired faculty members or Ph.D. students do not file their papers in the institutional system, or they sometimes do it even before the paper appears in WoS, not to mention many problems with affiliations and name disambiguation.

An analysis that we have performed on data retrieved from an institutional database is shown in [8]. We have extracted data about narrow scientific field assigned to each member of the teaching stuff and we have classified their papers according to WoS categories, using fractional counting in cases when the journal belonged to multiple categories. For groups of people elected for the same narrow scientific field we have identified three leading WoS categories. We have found 14 narrow scientific fields and the best matching to three leading WoS categories could be done for Technical Acoustics, Applied Mathematics and Power Systems, while people elected for the narrow scientific field of Computer Engineering and Informatics had papers in many different categories, where 40.5% belonged to CS, Software Engineering, CS, Information Systems and Engineering, Electrical & Electronic.

For the analysis we present here, we have used a dataset retrieved directly from WoS, using a query with the name of our School in the address field, for the timespan 2013-2023. After identifying 861 papers published in journals with impact factor, we have extracted distribution over journals to find out in which journals our teachers published at least 5 papers (Table 4). Each paper has at least one coauthor with the affiliation of the School of Electrical Engineering in Belgrade. All papers were extracted in order to analyze combinations of WoS categories as well.

TABLE IV
JOURNALS WITH FIVE OR MORE PAPERS IN THE DATA SET

NUCLEAR TECHNOLOGY RADIATION PROTECTION	38
IEEE ACCESS	26
SENSORS	22
IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION	15
ADVANCES IN ELECTRICAL AND COMPUTER ENGINEERING	14
ADVANCES IN COMPUTERS	13
ELECTRIC POWER SYSTEMS RESEARCH	12
EUROPEAN JOURNAL OF NUCLEAR MEDICINE AND MOLECULAR IMAGING	12
PHYSICA SCRIPTA	12
THERMAL SCIENCE	12
ELECTRONICS	11
INTERNATIONAL JOURNAL OF ELECTRICAL POWER ENERGY SYSTEMS	11
RADIATION PROTECTION DOSIMETRY	10
ENERGIES	8
ENERGY	8
IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES	8
INTERNATIONAL JOURNAL OF ELECTRICAL ENGINEERING EDUCATION	8
INTERNATIONAL JOURNAL OF PHOTOENERGY	8
IEEE TRANSACTIONS ON POWER DELIVERY	7
IEEE COMMUNICATIONS LETTERS	6
INFORMACIJE MIDEM JOURNAL OF MICROELECTRONICS ELECTRONIC COMPONENTS AND MATERIALS	6
INTERNATIONAL TRANSACTIONS ON ELECTRICAL ENERGY SYSTEMS	6
JOURNAL OF ELECTRICAL ENGINEERING ELEKTROTECHNICKY CASOPIS	6
JOURNAL OF LIGHTWAVE TECHNOLOGY	6
MICROWAVE AND OPTICAL TECHNOLOGY LETTERS	6
VACUUM	6
CERAMICS INTERNATIONAL	5
IEEE TRANSACTIONS ON ENERGY CONVERSION	5
IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING	5
IEEE TRANSACTIONS ON POWER ELECTRONICS	5
IET GENERATION TRANSMISSION DISTRIBUTION	5
JOURNAL OF PROCESS CONTROL	5
LIGHTING RESEARCH TECHNOLOGY	5
OPTICS EXPRESS	5
PHYSICAL REVIEW B	5

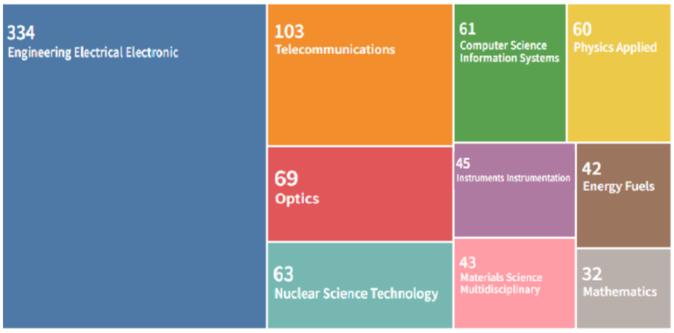

Fig. 4. Distribution of papers in the dataset over WoS categories

Analytics by WoS distribution of papers over WoS categories of the journals is presented in Figure 4. Leading category Engineering Electrical Electronic shows that the basic orientation towards electrical engineering is still present. Considering leading publishers, 169 papers are published by IEEE, 154 by Elsevier, and 68 by Springer Nature.

TABLE V
NUMBER OF PAPERS BY A COMBINATIONS OF WOS CATEGORIES

Engineering, Electrical & Electronic	103
Engineering, Electrical & Electronic; Telecommunications	43
Nuclear Science & Technology	40
Computer Science, Information Systems; Engineering, Electrical & Electronic; Telecommunications	29
Mathematics, Applied; Mathematics	24
Physics, Multidisciplinary	23
Chemistry, Analytical; Engineering, Electrical & Electronic; Instruments & Instrumentation	22
Computer Science, Artificial Intelligence; Engineering, Electrical & Electronic	18
Optics	18
Radiology, Nuclear Med. & Medical Imaging	16
Multidisciplinary Sciences	13
Telecommunications	13
Thermodynamics	12
Automation & Control Systems; Engineering, Electrical & Electronic	11
Computer Science, Information Systems; Engineering, Electrical & Electronic; Physics, Applied	11
Education, Scientific Disciplines; Engineering, Electrical & Electronic	10
Energy & Fuels	10
Environmental Sciences; Public, Environmental & Occupational Health; Nuclear Science & Technology; Radiology, Nuclear Medicine & Medical Imaging	10
Physics, Applied	10
Robotics	10

V. CONCLUSIONS

In this paper we have analyzed the position of the School of Electrical Engineering among other schools/faculties of the University of Belgrade, through simultaneous applications of candidates for enrollment, using social network analysis.

In the network with 31 schools/faculties as nodes and numbers of simultaneous applications as weights of 202 edges, the network diameter was 3. Average node degree was 13, ranging from the degree 0 of a single isolated node in Bor, to the max degree 22 of the Faculty of Agriculture. School of Electrical Engineering is slightly above average with its degree of 15, but its weighted degree centrality of 891 is ranked second, just after Faculty of Organizational Sciences with the highest value of this parameter that equals 1498. Grouping into communes shows that School of Electrical Engineering belongs to the same group with 6 technical faculties, Faculty of Mathematics and Faculty of Physics, but its strongest connections are with faculties which have relatively similar programs in computing.

The second analysis examined wish lists of modules after the common first year of studies at the study program of Electrical Engineering and Computing. Results were presented by distance matrix between modules, which may be regarded as a result of traditional organization of divisions that existed at the time before Bologna process.

The analysis of WoS categories of papers published by teaching staff of the School of Electrical Engineering shows that Engineering, Electrical & Electronic is predominant, both individually and in combination with other categories (Table 5). Our future work will include other schools in Serbia in the field of electrical engineering and computing.

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