A Hierarchical Fuzzy Model for Assessing Student's Competency

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Abstract. The aim of the study is to improve a system of competency' assessment, described in the Educational Program of the specialty. This assessment is based on a hierarchical fuzzy model in the fuzzyTECH program. The adequacy of proposed elaborated model is confirmed by a statistic agreement with thesis attestation results of Master of Arts. Besides, the model showed that combining the competency in the course of writing and attestation the Master of Arts thesis shall result in synergy effects.

The model input parameters consist of the data of academic assessment and the structure of the educational-professional program. These inputs simplify the process of assessing the competency while comparing with the existing approaches. Thus, stakeholders are able to assess the professional qualities of a graduate without requiring additional resources, because the model is built on the open source data such as the Educational Program of the specialty and the diploma supplement. The proposed model can assess the quality of educational-professional programs, and assist their comparative evaluation. The model's uniqueness is that output results of competency assessment are described both by linguistic terms, more common for employers, and numeric assessment, using 100-point scale, more common for students and teaching staff.

The main innovation of the model is its ability to assess adequately the obtained competency not only by the final learning outcomes, but also at any stage of the curriculum implementation. Therefore, the fuzzy model can also be utilized to predict the graduates' final performance, which enables students to apply the model for self-assessing of their own competency in a learning process. Such self-assessment may help students promote learning scores in the courses which is relevant to determined competency.

Keywords: Competency · Fuzzy logic · Fuzzy system · Students' assessment · Competency-centered curricula

1 Introduction

The Competency-based approach is an integral part of modern education which benefits a student for the learning process of his own life. However, the primary role and aim of a competency are the improvement of education and bridge a gap of talent

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requirement between universities and employers. Competency takes a role as a universal platform where employers propose their own requirements for talents, and universities in their turn are trying to satisfy them.

Terminological definition of competency along with their composition and methods of assessment are not unified within the industries, levels of education, and national educational systems. Various research works and practices of competency training for many years did not give clear answers to the consistency and mechanisms of their formation [1]. Competency-based research is still important to the field of education research.

A Variety of competency requirements in practice results in solving the mentioned problems in different ways. Thus, to promote comparable and compatible qualifications of graduates in the European Union, the European Higher Education Area was founded in 2014 [2]. Many industries, national and international standards are created and applied accordingly with a very detailed description of competency. On one hand, current situation contributes to a clear disclosure of the concept; on the other hand, the problems of evaluating to competency become more complicated in practice.

By reviewing major research works in the field, it helps find their confirmation and implementation experience in practice, parametrization is essential for evaluating all components of competency. With the help of parametrization, it can determine the high relevance of the development of applied assessment and analysis methods of competency. Therefore, when evaluation models are constructed, it needs to consider some vital factors such as: the interests and descriptive scales of different stakeholders, the existing academic information of the educational process, and simplifying the evaluation process, etc.

In this case, the object of the study was the elaboration of the assessment method of a new competency which should consider the following factors:

(1) on the basis of widely used standards of competency description;
(2) take into account of the available data set of a university graduate preparation and not require additional observations and/or expert assessment;
(3) possibly utilized by an employer assessment or by self assessment of a student;
(4) assess some separate competency components, as well as the comprehensive competency.

2 Background and Related Work

The concept of competency has been a common subject of research for many years. The term 'competency' was introduced in social science by McClelland [3] who tried to structure competency components by different skills of a person. Many stakeholders are interested in studying this phenomenon, including employers, university administration, government institutions, and even students, which results in interpreting the concept of competency in many ways [4]. For example, competency is described as connected pieces of knowledge, skills and attitudes that help to solve work-related problems [5]. The competency is also understood as the combination of the relevant cognitive, psychomotor and affective skills to perform a complex professional task [6].

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Other scholars define competency as a cluster of trained skills, knowledge and attitudes [7]. It is believed that competency is a complex phenomenon formed by a holistic combination of the components, such as knowledge, skills, strategies, attitudes, etc. [8]. In spite of the above-mentioned examples of the unanimity lack, many stakeholders suggest to study competency by taking into account the quality of an employee that ensures to fulfill a specific job requirements.

The need to use the concept of competency in the practice of employers and educational institutions boosts the development of detailed descriptions of each component in the form of standards. The most common among them are: State Educational Standards of Higher Professional Education; Final State Certification; The Simple Reusable Competency Map draft standard; Performance Based Competency Standards; Cross-disciplinary competency standards; The Specification of Competency Standards and others. Standards are approved at the level of country governments, employers' associations, associations of educational institutions and, even, some universities. Unfortunately, most standards contain only the system of quality indicators and this makes practical assessment to competency more complicated.

Training of a highly qualified specialist presupposes the acquisition of appropriate competency defined by the standards described above. That is why most universities have offered competency-oriented courses [9]. The basis of such training programs is the need to acquire the so-called ideal student competency [8]. However, the effectiveness of this approach also requires an adequate system of competency assessment. The system should identify the achieved competency within the course, the systematic assessment of competency training, and the interests of stakeholders [8]. The evaluation system may include different methods applied to different competency components without losing adequacy. Considering the overall competency of a student consists of a number of portion [6], the assessment to competency has to be carried out for all its portion.

Except employers, university administration and government institutions, students are interested in self-assessment to their competency as well. Formation of an efficient student-centered learning environment presupposes active involvement of students in evaluating their learning outcomes [10]. Every assessment method has its own impact on the learning process [6]. Thus, the assessment to the ability of a student to self-assess gained skills is considered to be a new complement potion for competency assessment.

However, the implementation of competency assessment methods is a sophisticated process. The obstacles of building such an assessment system include the reluctance of staff; the lack of empirical data [7]; the lack of universal scales for assessing competency, etc. However, the most complicating factor of the assessments described above is the qualitative nature of the competency that are often subjectively assessed by experts using numerical scales or linguistic descriptions, which contribute to the growing interest in the use of methods. However, the most complex factor of the assessment described above is the qualitative nature of the competency constituents that are often subjectively assessed by experts with the help of numerical scales or linguistic descriptions, which contributes to growing the interest in the use of methods of the Fuzzy Set theory in a comprehensive assessment of competency and other learning characteristics [10].

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Many examples of fuzzy logic models are known as those used for assessing competency. Though, the proposed methods solve the above-mentioned problem partly and for fairly narrow applied tasks. Thus, Adem Golec and Esra Kahya utilized a fuzzy model for competency-based employee evaluation and selection [11]. This fuzzy model had seven input factor block parameters and one output employee's competency parameter. The relation of input and output parameters, as well as the set of rules, were determined based on expert assessment data factor analysis of 53 indicators. Such a model is flexible when considering new parameters and is consistent with organization goals and strategies. However, the model has a lot of indicators that complicates its use. So, the model introduction, in the case of other organizations, requires the involvement of trained experts. The model does not contain generally recognized competency assessment standards, which complicates the comparative assessment to its functions.

Jevšček utilized 360° feedback to build a fuzzy model of competency assessment [12]. The model has two output parameters. The relation of the input and the output parameters, as well as the set of rules, was defined based on survey questionnaire analysis of 350 participants. The model, suggested by Matej Jevšček, has a few numbers of parameters that simplifies its application. Though the model does not contain the competency standardized parameters as those in Golec and Kahya method [11], the above mentioned shortcomings still exist in the model.

Another aspect of using the fuzzy approach is the attempt of ranking people by their competency in economics education suggested by Suleman and Suleman [13]. The model allowed assessing successfully, ranging and investigating the structure of the bundle of competency of 593 banking employees. However, the suggested model does not consist of the competency standard system, it is highly specialized. The possibility of using the model in the learning process is somewhat complicated, especially the possibility of self-assessment to students for acquired competency.

Kavčič and others built a fuzzy student model based on the use of the competency graph [14]. The model determined the categories of competency considering their real performance. The model can assess the competency level in the learning process using the student knowledge assessment system. Such approach allows the student to influence the learning results, and can motivate students to acquire the missing competency. Though, similar to the above-mentioned models, the method suggested by Kavčič and others [14] is not based on common assessment standards of competency, which suggests the use of this method is not favorable among employers. The applied possibilities of the model are also limited by the complexity of self-assessment to acquired competency conducted by a student.

Therefore, the development of using Fuzzy Logic is relevant to the research field of competency and it requires further research. Also, most methods of assessment to competency are complex and contain a hierarchical internal structure. They are normally parametrized by qualitative and quantitative methods, which take into account with a large amount of data and provide compatibility with scales of generally accepted standards, etc.

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3 Methods and the Model

The Fuzzy logic theory was introduced in the work of Zadeh [15]. The main idea of the theory was the mathematical description of linguistic vagueness. Further development of Fuzzy logic was possible due to the ability of describing problems with a degree of non-statistical uncertainty [16] that was not resolved through probability theory [17]. Fuzzy set theory describes these problems in the form of simple linguistic terms, which can subsequently be processed by mathematical operators [18].

Relying on the fuzzy logic approaches, there was an attempt to build a fuzzy model for assessing student competency. As a research object, an educational program (further EP) of the second level of higher education chosen for ‘Economic Cybernetics’ (2018), which is available on the site of Kyiv National University of Trade and Economics [19]. The structure and EP courses are determined according to the National Competency Standards of Ukraine and meet the requirements of the competency-centered courses. An EP contains a detailed description of the course and the final competency of a graduate. For each course of the program, there is a description of the competency training objective (Table 1).

Program Competence (further PC) lines correspond to the competency that a student should achieve. PC1 shows ‘The ability for pre-project analysis and modeling economic objects and tasks’, PC2 – ‘The ability to elaborate the projects of information systems or their fragments’, PC3 – ‘The ability to elaborating managing consulting projects’, PC4 – ‘The ability to elaborate the forecasting development models of economic processes and systems’, PC5 – ‘The ability to manage the projects of informatization of social and economic objects of different level’, PC6 – ‘The ability to assist a system or a program complex’. Columns CC correspond to the compulsory courses and OC to the optional courses of professional training. CC1 stands for the course ‘Theory and practice of scientific research’, CC2 – ‘Mathematical methods and models of complex economic systems’, CC3 – ‘Information security’, CC4 – ‘Applied system analysis, CC5 – ‘Techniques of data analysis’, CC6 – ‘Stochastic models in economy’, CC7 – ‘Techniques of mobile applications development’, OC1 – ‘Corporate information systems’, OC2 – ‘Enterprise risk management’, OC3 – ‘Corporate network management systems’, OC4 – ‘Internet security’, OC5 – ‘Financial management’.

Table 1. Program competences and educational program components matrix[a]

	CC1	CC2	CC3	CC4	CC5	CC6	CC7	OC1	OC2	OC3	OC4	OC5
PC1	+	+		+		+		+		+		+
PC2			+					+		+	+	
PC3									+	+		+
PC4		+			+	+	+	+		+		+
PC5			+					+			+	
PC6			+		+		+	+		+	+	

[a]built on the basis [19]

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Academic courses contributing to the acquisition of one or more competency marked with a "+" sign (Table 1). Each competency can also be formed within a range of courses. Despite the detailing of the process of acquiring competency in these types of documents, the numerical assessment of the competency of a graduate is complicated in practice and needs further analysis.

For this study, the input data of a competency assessment system include selected students in a scale of 100 scores in each course and the structure of competency determined by the EP. For the fuzzyfication of input and output parameters we used the trapezoidal and triangular membership function (Table 2), which are utilized for assessing the student's performance [20]. Marginal scales of the fuzzy set input, intermediate and output data were the same to get better interpretation of the modeling results.

Table 2. Fuzzy set of the model

Variable	Type of variable	Linguistic term	Membership function	Interval
Final grade of courses: CC, OC	Input	Low	Trapezoidal	(60, 60, 70, 80)
		Medium	Triangular	(70, 80, 90)
		High	Trapezoidal	(80, 90, 100, 100)
Competency: PC1…PC6	Intermediate	Low	Trapezoidal	(60, 60, 70, 80)
		Medium	Triangular	(70, 80, 90)
		High	Trapezoidal	(80, 90, 100, 100)
General competency of a graduate: PC	Output	Very low	Trapezoidal	(60, 60, 66.7, 73.3)
		Low	Triangular	(66.7, 73.3, 80)
		Medium	Triangular	(73.3, 80, 86.7)
		High	Triangular	(80, 86.7, 93.3)
		Very high	Trapezoidal	(86.7, 93.3, 100, 100)

Figure 1 and Fig. 2 show graphical interpretation of Fuzzy sets (formed in fuzzyTECH 5.54d) of input CC1 and middle PC1 parameters. Linguistic terms are depicted here graphically: the red curve corresponds to the 'low' parameter (trapezoidal membership function), the green one to the 'medium' parameter (triangular membership function) and the blue one to the 'high' parameter (trapezoidal membership function).

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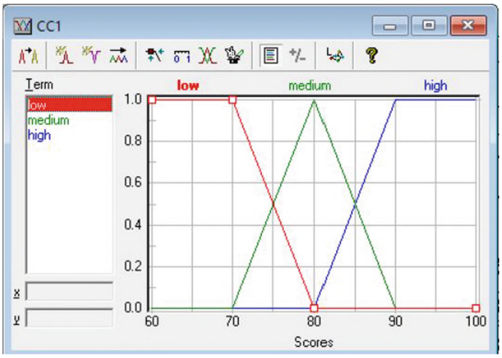

Fig. 1. Fuzzy sets of CC1 input parameter

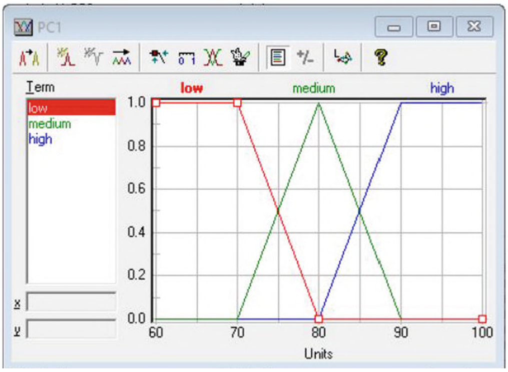

Fig. 2. Fuzzy sets of PC1 middle parameter

The next stage contained the implementation of the table of competency correspondence and educational program components (Table 1) in the form of a hierarchical fuzzy model (Fig. 3).

The model contains 12 input fuzzy parameters that are set according to the student's progress in the indicated courses. Fuzzy parameters containing the acquired competency are defined as intermediate. Six blocks of rules are formed by the courses input parameters based on Table 1, and the output parameters are corresponding competency.

The rules were determined by the Mamdami technique [21] for fuzzy decision-making and fuzzy inference. The set of rules that determine input and output membership functions were automatically selected in the fuzzyTECH environment.

The rules are determined by the 'If-Then' conditions for all blocks PC_1, PC_2, PC_3, PC_4, PC_5, PC_6, PC. The example of the rule settings for block 'PC_3' is shown in Table 3.

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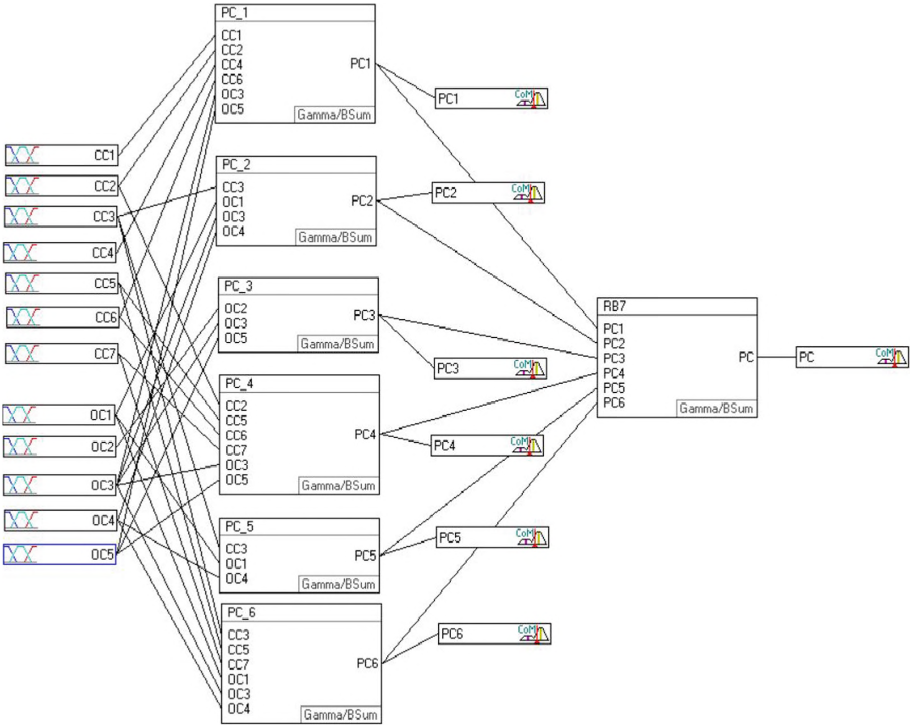

Fig. 3. Hierarchical fuzzy model for assessing the acquired competency

For the Fuzzy rule computation of the model, the compensatory operator ($\lambda = 0.046$) is employed:

$$\mu = (1 - \lambda) \min_{i=1..n}(\mu_i) + \lambda \sum_{i=1}^{n} \mu_i / n \tag{1}$$

The Center of Maximum method is used as a defuzzification method for output parameters:

$$x_{OUT} = \frac{(x_1\mu_1 + x_2\mu_2 + \ldots + x_n\mu_n)}{(\mu_1 + \mu_2 + \ldots \mu_n)} \tag{2}$$

The model is composed of two levels for assessing the total competency of a student, a PC block is employed as supplement of the model. The above described methods for making rules and defuzzifying the output parameter (general competency) were applied for this block.

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Table 3. Set of rules for rule block 'PC_3'

IF			THEN	
OC2	OC3	OC5	DoS	PC3
Low	Low	Low	1.00	Low
Low	Low	Medium	1.00	Low
Low	Low	High	1.00	Medium
Low	Medium	Low	1.00	Low
Low	Medium	Medium	1.00	Medium
Low	Medium	High	1.00	Medium
Low	High	Low	1.00	Medium
Low	High	Medium	1.00	Medium
Low	High	High	1.00	High
Medium	Low	Low	1.00	Low
Medium	Low	Medium	1.00	Medium
Medium	Low	High	1.00	Medium
Medium	Medium	Low	1.00	Medium
Medium	Medium	Medium	1.00	Medium
Medium	Medium	High	1.00	High
Medium	High	Low	1.00	Medium
Medium	High	Medium	1.00	High
Medium	High	High	1.00	High
High	Low	Low	1.00	Medium
High	Low	Medium	1.00	Medium
High	Low	High	1.00	High
High	Medium	Low	1.00	Medium
High	Medium	Medium	1.00	High
High	Medium	High	1.00	High
High	High	Low	1.00	High
High	High	Medium	1.00	High
High	High	High	1.00	High

4 Results Analysis and Discussion

To test effects of the model (Fig. 3), it has studied a case of students of 'Economic Cybernetics' specialty of Chernivtsi Institute of Trade and Economics of KNUTE. Additional data collection or process are not required while acquiring the information about the students' learning outcomes, as well as the EP structure. The analyzed sample comprised the information about the studying results of 17 students. The sample was made on the basis of the data collected in 2016–2018 by the co-author Y. Koroliuk. The criteria of the sample data contain students with different learning outcomes in the scope of the courses and their average performance (Table 4).

Entering input data in the model (Fig. 3), the outcomes *x* of intermediate fuzzy competency parameters are obtained in the fuzzyTECH environment (parameters PC1,

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PC2, PC3, PC4, PC5, PC6 of Table 4). The results show the presence of different assessments of acquired competency by their types, depending on the outcomes of studying courses as the constituent parts according to EP. Figure 4 shows an example of defuzzification of the output competency of student number '5'.

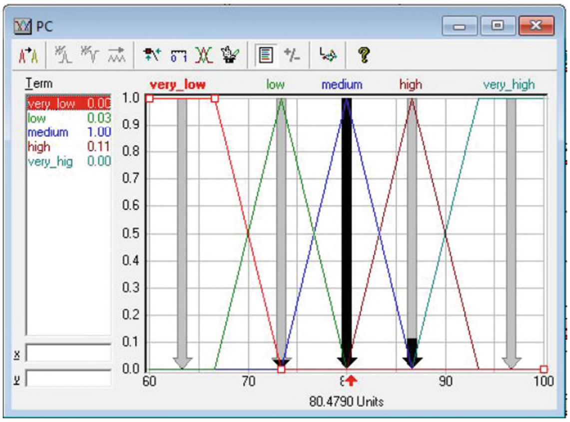

Fig. 4. Example of graduate's general competency (PC)

Table 4. The learning outcomes of students, studying the courses within EP and the results of competency assessment

ID of student		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Input parameters	CC1	63	63	77	82	90	79	81	88	78	87	85	90	70	88	84	92	90
	CC2	62	64	61	77	82	81	79	81	83	86	89	88	71	86	90	94	93
	CC3	69	65	69	71	90	82	80	78	83	87	81	85	98	89	84	91	90
	CC4	68	67	78	65	75	76	79	76	88	87	81	85	73	86	90	86	92
	CC5	70	69	72	80	69	79	79	80	88	88	89	85	72	89	90	92	92
	CC6	67	66	68	85	90	85	81	90	82	85	90	87	85	90	90	89	90
	CC7	70	72	67	90	80	82	79	79	85	84	87	88	95	86	90	94	93
	OC1	65	66	71	82	65	76	82	78	87	84	87	87	93	87	85	85	92
	OC2	69	71	63	79	68	78	77	89	84	86	90	87	97	88	83	91	90
	OC3	61	69	78	73	73	77	82	88	81	87	82	87	98	89	88	86	93
	OC4	62	67	79	78	77	82	78	89	83	83	87	87	95	85	87	90	91
	OC5	67	67	64	85	90	78	80	77	84	83	88	86	98	87	90	92	91
	Average score	66	67	71	79	79	80	80	83	84	86	86	87	87	88	88	90	91
Attestation of MA thesis		60	65	72	82	82	80	86	87	87	90	90	91	93	89	92	92	93
Output parameters	PC1	63	63	65	79	91	73	88	88	87	87	95	87	80	87	95	95	95
	PC2	63	63	67	73	77	79	81	79	88	91	89	92	95	87	92	95	95
	PC3	63	63	65	82	80	77	83	93	91	93	95	94	95	95	95	95	95
	PC4	63	63	65	85	81	80	73	86	87	87	87	87	90	87	95	95	95
	PC5	63	63	67	78	80	84	83	87	92	93	93	94	95	95	93	95	95
	PC6	63	63	65	80	77	87	73	80	87	87	87	87	95	87	95	95	95
	PC	63	63	68	80	81	80	84	84	88	91	88	88	95	88	95	95	95

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The level of acquired competency could be different even in the case of similar average performance. Such results confirm the elaborated model's application for more accurate and adequate assessment for the overall student's competency and its components. For assessing other types of EP, the model should be adjusted in accordance with structure of the rule blocks.

To check the accuracy of calculated competency, the results of Master of Arts (MA) thesis attestation were taken into consideration (Table 4). The work on the MA thesis and their attestation presupposed the application of all the professional competency which were acquired during the course study. That's why the concordance of the mentioned indices from the general competency output data of the model can be the affirmation of its adequacy.

Figure 5 presents the results of the calculated general competency (PC), average performance and attestation of MA theses of students during the course study. As the figure presents, general competency indices concord with the results of MA theses attestation more accurately for all areas, they are marked by criteria 'Very low', 'Low', 'Medium', 'High', 'Very high'. The analysis result of the significance of given index model description reveals that the value of index R^2 was equal to 0.95 which is higher than its minimum critical value. Standard error equals to 2.38 and the value of index F (equals to 298.4) is always much smaller than the critical value, and the value of calculated α (significance of F) is close to zero.

Thus, general competency indices, calculated by the model, confirm the peculiarities of MA theses attestation results are higher than the indices of average performance (Fig. 5), which never had an exact explanation before.

The model confirms that the combination of competency components in the process of writing and attestation of MA thesis leads to synergy. Thus, the result obtained in the course of the MA thesis attestation is higher than the arithmetic mean of the course performance results.

Statistic confirmation of the model's adequacy allows the use for the accurate prediction of the final student performance of studied specialty. In addition, the model makes possible to estimate the general competency components values quantitatively (PC1…PC6 see Table 4), which could be previously assessed by qualitative methods only.

Wide application of this method in practice for an employer's assessment or student self-assessment requires the model only numerical data of the courses' learning outcomes (available in a diploma supplement), which significantly simplifies the calculations. The result can be calculated by using numerical or linguistic scales which can be unequivocally interpreted by various stakeholders.

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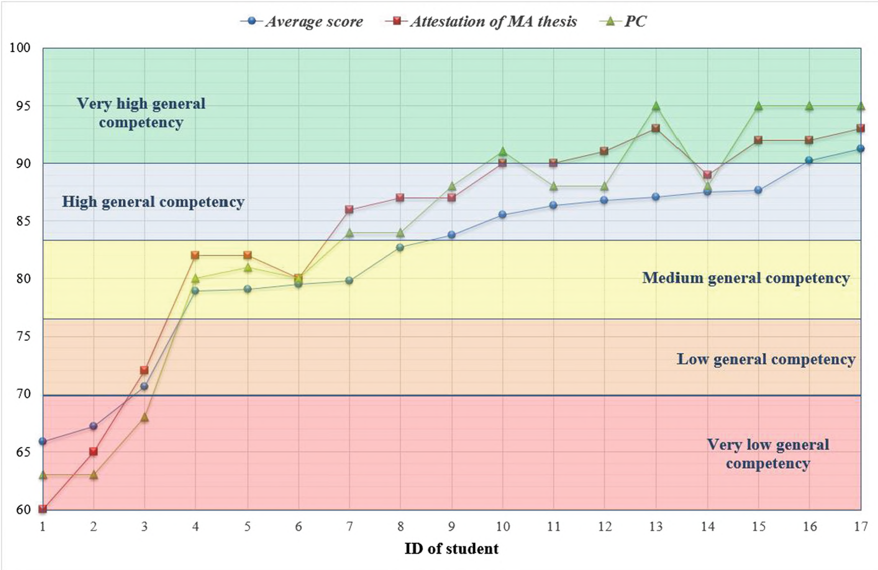

Fig. 5. General competency (PC), average performance and attestation of MA thesis for the analyzed sample

5 Conclusion, Limitations and Future Work

The paper reveals that the proposed fuzzy model is capable to improve the system of competency assessment, described by the standards of the specialty (EP). For the calculations, the model just utilizes learning outcomes data and the structure of the EP, which simplifies the process of assessing competency. When using the model based on open source data, additional resources to assess the professional qualities of students are not required by stakeholders any more.

The adequacy of the obtained modeling results is confirmed by the statistical agreement with the MA thesis attestation results. In addition, the model confirmed that the combination of competency in the course of writing and attestation of MA thesis leads to synergy. Thus, the model is capable of carrying out an adequate assessment to each component and overall competency. Also, the model can assess the quality of EPs, carry out their comparative assessment, etc. The fuzzy model can be used for predicting the final performance of students. Thus, a student can be encouraged to adjust his or her learning methods in those courses that make a more significant contribution to the chosen competency and achieve better scores.

As input parameters, this study adopts a performance rating of 100 scores, which causes the model's limitations. For the universities with a different performance rating, the proposed model needs to be revised accordingly. The results of the model also provide an opportunity to assess the competency for students defined by the EP. Further work includes the development of the proposed model by considering other competency

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related parameters beyond the proposed EP list. In particular, psychological, behavioral, motivational, and cognitive parameters will be incorporated in future model for accurately assessing students' competency.

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