The Assessment of Importance of Selected Issues of Software Engineering, IT Project Management, and Programming Paradigms Based on Graphical AHP and Fuzzy C-Means

Paweł Karczmarek
Department of Computer Science
Lublin University of Technology
Lublin, Poland
pawel.karczmarek@gmail.com

Witold Pedrycz
Department of Electrical & Computer Engineering
University of Alberta
Edmonton, Canada
Department of Electrical and Computer Engineering
King Abdulaziz University
Jeddah, Saudi Arabia
Systems Research Institute
Polish Academy of Sciences
Warsaw, Poland
wpedrycz@ualberta.ca

Dariusz Czerwiński
Department of Computer Science
Lublin University of Technology
Lublin, Poland
d.czerwinski@pollub.pl

Adam Kiersztyn
Department of Computer Science
Lublin University of Technology
Lublin, Poland
adam.kiersztyn.pl@gmail.com

***Abstract*—In this study, we present the results of surveys conducted in a group of employees and students of IT faculties presenting the answers to the most important, in our opinion, issues related to software engineering (SE), IT project management, and programming paradigms. The above topics are chosen because of their high relevance to the professional community. The participants taking part in the experiments quantified their input through the process of pairwise comparisons (a so-called Analytic Hierarchy Process, AHP) using an innovative highly interactive approach based on a graphic communication means. The generic AHP method was augmented by the optimization mechanisms delivered by the Particle Swarm Optimization (PSO) in order to deliver the highest possible consistency of responses of the participants. Moreover, we demonstrate a method based on Fuzzy C-Means (FCM) filtering highly inconsistent and unreal experts' assessments. In a series of experiments, we demonstrate the accuracy and stability of the AHP method based on graphical environment. We discuss two variants of aggregation of experts' opinions according to their level of experience in the field of interest. Finally, we show the efficiency of the FCM as the method of preselection of experts' evaluations.**

***Index Terms*—AHP, Analytic Hierarchy Process, Particle Swarm Optimization, Fuzzy C-Means, non-linear transformation, graphical tools**

Funded by the National Science Centre, Poland under CHIST-ERA programme (Grant no. 2018/28/Z/ST6/00563).

I. Introduction

Software engineering, as well as closely related IT project management and programming paradigms, play a vital role in the student education process and the corresponding program content has an impact on the daily work of practitioners. Moreover, the topics related with these subjects have also posed significant challenges for researchers dealing with these issues due to the pace of development of the IT industry and the growing needs of institutions using its services. Therefore, it becomes important to find the answer to the timely question about educational needs that should be provided for future IT graduates in this area and to learn their point of view on this issue.

Therefore, the main goal of this study is to find answers to the two questions in the field of software engineering, namely (i) what are its (SE) most important challenges for the future developments and (ii) which part of the software life cycle is given the most attention. In addition, we ask about the main reasons behind failures of IT projects and about the best (most effective) management methodologies. Finally, we are interested in learning to which extent representatives of the IT industry understand the functional paradigm in programming and with what programming language they use.

Moreover, we are interested in an in-depth analysis of the AHP method of pairwise comparisons with relatively large

978-1-7281-6932-3/20/$31.00 ©2020 IEEE

number of experts taking part in the experimental session. We use an innovative approach to the AHP, namely augment it by a graphical tool such as slider, to enable the users to answer the questions in possibly easiest way without resorting to the numeric or linguistic scale. This way of working with AHP allows the users to work with uncertain and imprecise answers (no scale) what can be modeled using, for instance, fuzzy sets, see [1].

Finally, our goal is to present a novel method based on Fuzzy C-Means (FCM) [2] algorithm to filter highly inconsistent experts' opinions. They may be the pairwise comparisons completed somehow randomly. On a basis of FCM we are able to apply a preselection technique to work only with reliable opinions of individual experts. Therefore, the final result of group decision can be significantly improved in the terms of consistency.

Due to the significance of the issues, there have been numerous important studies in software engineering [3]–[6], etc., IT project management [6]–[9], etc. and guidelines devoted to almost all programming languages. The issues were also widely discussed in the literature [10]–[29] and on practitioners' websites [30]–[35] among many others. In particular, to the task of questions inspired us the following sources [30], [32], [33], [35] and our own experience with theory, practice as well as teaching students in the fields of questionnaires.

In the literature of SE, Analytic Hierarchy Process [36] has been applied to very specific tasks or problems such as a choice of a suitable software project management tool [37], quantification of McCall's quality factors [38], or prioritization of software requirements [39]. Here, we use AHP to discuss more general problems that arise when working on almost any type of IT system.

The originality of our research lies in the fact that it is to our best knowledge, one of the first carefully organized studies of the subject in the field of software engineering and its challenging problems using AHP. In addition, an innovative approach to AHP was used, based on the graphic environment. This AHP augmentation makes it possible to enable people completing surveys in the way which is independent of analyzing and thinking about the classic scale of integer numbers from 1 to 9 (or 1 to 7) or the linguistic meaning of the description of this scale's points. It should be noted that making it easier for respondents to answer difficult questions in the field of software engineering using simple graphic components is important in the case of the environment of people working in the IT industry, for which time is of paramount importance. In addition, the innovation of our research lies in the use of optimization techniques to unify expert responses in large collections of respondents. Moreover, we learned from surveys how the awareness and knowledge of people in the IT industry about important issues in the field of IT project management, software engineering and basic programming paradigms is depending on their experience and status in the labor market (still studying, studying and at the same time working, and working). Finally, the Fuzzy C-Means algorithm was used to preselect the reliable expert opinions.

Here, it should be emphasized that the list of literature in this study is extensive. However, due to the wide range of topics, it is difficult to narrow it down to a smaller number of items.

The structure of the paper is as follows. In Section II, we recall the concept of Analytic Hierarchy Process. Section III is devoted to its graphical version based on graphical components and an application of FCM. Section IV presents the analysis of experimental results. Finally, conclusions and directions of future work are presented in Section V.

II. Analytic Hierarchy Process

AHP (Analytic Hierarchy Process [36], [40] is a well-known group decision-making tool commonly applied to prioritize, quantify, or rank the features according to one or more experts' preferences. Due to its in-built mechanism of auto-correction based on the concept of consistency the pairwise comparison process has found many followers and users, see, e.g., [41], [42]. The underlying idea can be outlined as follows. The expert has to estimate his/her judgements related to all the pairs of n alternatives. The result of this consideration is collected in a form of an $n \times n$-dimensional matrix A. The matrix has the property of reciprocity, namely $a_{ij} = 1/a_{ji}$, $i, j = 1, \ldots, n$. Of course, this implies that $a_{ii} = 1$. Users generally make their choices expressing their opinions on a 9-point scale with the following quantification: 1 - equal importance, 2 - weak importance, 3 - moderate importance, 4 - moderate plus, 5 - essential (or strong) importance, 6 - strong plus, 7 - very strong (or demonstrated) importance, 8 - very, very strong, and 9 - extreme importance. While a 9-point scale is commonly encountered, there are shorter scales as well.

Now, let us discuss the concept of consistency. One uses the following formula to quantify consistency $\nu = (\lambda_{max} - n) \,/\, (n-1)$, where λ_{max} is the highest eigenvalue of A, to estimate the quality of the pairwise comparison process, see [40], [43], [44].

A so-called consistency ratio is expressed as $\mu = \nu/r$. Here, r is some constant determined through a series of experiments reported in [45] for the first integer values of n (it is 0, 0, 0.52, 0.89, 1.11, 1.25, 1.35, 1.40, 1.45, 1.49 for $n = 1, 2, \ldots, 10$, respectively). However, higher values of r were also considered in the literature [43], [44]. If this value is relatively low, the process can be continued. If the values are too high (say, higher than 0.1) the procedure may be repeated.

The final rankings of compared features are related with the values of eigenvector associated with the eigenvalue λ_{max}. An interesting aspect of the method is the approach to the aggregation of more than one expert responses. Generally, there are two models. First of them is to find average priorities of the experts' priorities. They can be, for instance, weighted on a basis of consistency of particular experts' reciprocal matrices. The second approach is based on the geometric mean of all the experts' reciprocal matrices. The two ways of aggregation were shown, among others, in [46].

III. Graphical Enhancement of the AHP and an Application of Fuzzy C-Means

A. Graphical AHP

Here, we recall a model of the AHP graphical enhancement. Users, despite the intuitive appeal of the AHP method, have sometimes difficulties in understanding the linguistic or numeric AHP scale, particularly, when they are not used to apply the method in their day-to-day practice. Therefore, an introduction of intuitive graphical tool can be an important innovation in the process of pairwise comparisons. In [1], [47] proposed was an application of use of the slider or dial arc to get the numerical values of the experts' preferences. Here, we use this method (namely, slider) again to obtain the final ranking of many experts in the field. The overall procedure is outlined as follows:

1) Collect answers from the experts.
2) Transform the answers (positions of the sliders) to the floating point on the $[1/9, 9]$ scale. This can be obtained on a basis of some transformation. This function depends on the number of slider's values and their range, for instance 0 – 100 if the data are expressed as the percentage values. In this particular case the function reads as

$$t\left(x\right) = 2/625x^2 - 8/25x + 9 \tag{1}$$

Here, an assumption is a sufficient number of slider's hidden bars. This is used so that the user has full freedom to move the slider without feeling the differences between its subsequent hidden values.
3) Use the reciprocal matrices to find the individual preferences.
4) Find the non-linear transformation of the reciprocal matrices based on piecewise linear function to decrease the inconsistency index of the method. The transformation can be obtained using any optimization method, e.g., PSO [48] according to the sum of the inconsistency ratios yielded from each reciprocal matrix.
5) Determine the final ranking of the priorities.

The general form of the piecewise linear function is as follows.

$$f\left(x\right) = \frac{\left(b_i - b_{i-1}\right)\left(x - a_{i-1}\right)}{a_i - a_{i-1}} + b_{i-1}, \quad x \in \left[a_{i-1}, a_i\right) \tag{2}$$

for $x \geq 1$ and a_i, b_i from the range $[1, 9]$, $i = 1, 2, \ldots, p+1$, are the coefficients to be found. If $x < 1$ the value of the function reads as $1/f\left(1/x\right)$.

For the group of m experts we have reciprocal matrices, say $R_1, R_2, \ldots, R_m$ (of course, they contain the values from the range $[1/9, 9]$). The goal is to determine the coefficients of f with an assumption that the indices μ_k are minimal, namely

$$\arg \min_{a_2 < \ldots < a_p, b_2 < \ldots < b_p} \sum_{k=1}^{m} \mu_k \tag{3}$$

This can be easily obtained using PSO, see [1], [47] for details. Note that one has to retain the following inequalities: $a_{i-1} < a_i$ and $b_{i-1} < b_i$. Therefore, it is worth considering the increments $\Delta_i = a_{i+1} - a_i$ and $\delta_i = b_{i+1} - b_i$, $i = 1, \ldots, p$, instead of the original coefficients a_i, b_i forming the search space in which the optimization is carried out.

At the end of the iterative procedure, we apply the function $f\left(x\right)$ to all of the m matrices and determine the final priorities as the average of the eigenvectors.

B. An Application of Fuzzy C-Means

Sometimes it is possible to obtain highly unreliable opinions, for instance, from students, who are not interested in fulfilling the questionnaires or someone who wants to complete the pairwise comparisons very quickly. One of the possible methods preventing form the consistency of initial data might be to apply well-known technique based on Fuzzy C-Means. When relatively large group of experts assess pairs of features, many opinions may be totally different. However, it is possible to group these series of answers coming from experts. The values of the series can be the vectors of sequential slider's positions values. The dimensionality of the vector is $d = n(n-1)/2$. Using the FCM algorithm carried out in such d-dimensional space we obtain c clusters; c is a natural number greater than 1. Fuzzy C-Means in d-dimensional case has an interesting property such that the memberships of the records (vectors) of the dataset are almost equal to all the clusters, see, e.g., [49]. Of course, in general use, such information is of low value. However, if one cluster is very "far" from the others a vast majority of vectors belong almost equally to all the clusters except this one. Then, obviously, the vectors of answers seem to be acceptable. The answer vectors for which the membership to the outlying cluster is greater that to the other clusters can be removed from considerations.

IV. Numerical Experiments

In the series of experiments, we have asked our students, lab members, and colleagues from local IT companies to answer the questions when running the AHP process. They were asked to answer six questions, namely

1) What are the most important challenges for the future of software engineering (changes management, the problem of scalable systems building, work with big data sets, work with AI, testing, communication & requirements understanding, meeting deadlines).
2) Which part of the software life cycle is given the most attention to you (requirements analysis, design, implementation, testing, deployment, maintenance)?
3) What is the most important reason of IT project failures (incomplete requirements and specifications, no user involvement, no resources, unrealistic expectations, lack of management support, requirements changes, no planning, the project is no longer needed)?
4) Which methodology of leading IT projects is most efficient (Agile, Scrum, Lean, Waterfall, Six Sigma, Kanban, PMI/PMBOK, Prince2)?
5) Which paradigm of programming is mostly preferred by you (structural, objective, functional, logical)? and

6) Which of the most popular programming languages are the best to work in functional programming paradigm (Java, JavaScript, Python, C#, C, C++, Haskell)?

The questionnaire was built using well-known tool [50] and the participants were to answer the above questions in the form presented in Fig. 1. The group of respondents is composed of 102 people who are members of our laboratory, friendly employees from the IT industry and our students of the third and fifth year of study. However, the survey was anonymous. 55 people declared they were studying. 32 people checked the option "I study and work", while 15 people declared that they work. In the case of the first question, the respondents within each group decided that the biggest challenge currently facing software engineering is the problem of understanding requirements and communication (widely understood). On the other hand, it was agreed that the construction of scaled systems is not a significant problem (see, Fig. 2). Question no. 2 was an interesting case. Students found that the implementation part of the project usually takes the most effort. People who work (including working students) believe that system design takes the most time. Such results are not surprising, because usually students focus on coding specific tasks, less focus on developing requirements, their analysis, testing the solution, and the least on its deployment. Similarly, requirements analysis took a higher place in the ranking of practitioners. Students put the testing problem in second place (Fig. 3). The results of the next issue are presented in Fig. 4. Unrealistic expectations are, according to the respondents, the main cause of project failures. However, students in the second place see incomplete requirements and specifications, while practitioners see more clearly the problem of changes in requirements and lack of proper planning. Students do not notice the problem of lack of support in project management at all, which seems to be borne in mind by people with experience in working in the IT industry. The perception of different design methodologies is also different depending on whether the respondent is a student or an employee. Students chose Agile methodology as the best, and Scrum as the second. Practitioners also value Kanban methodology, but also Prince2 and Waterfall, see Fig. 5. The fifth question, which seems easy enough, has made a lot of effort to answer. This seems to be dictated by the lack of knowledge of the naming of programming paradigms. Everyone prefers object-oriented methodology for software development, but seems to confuse the functional and structural paradigm (Fig. 6). The last question was quite tricky. Practitioners and senior students knew that Haskell pursues a functional paradigm. Many people also did not realize that lambda expressions are already present in C++ (since C++ 11), see Fig. 7.

An important aspect of our survey is the consistency of results. In particular, a group of respondents describing themselves as working and studying resulted in very inconsistent answers. The method based on PSO optimization has reduced this inconsistency significantly, however, not at all. Table I shows the results by which value this factor has been improved. In addition, Fig. 8

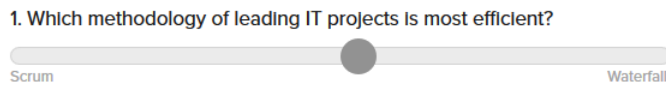

Fig. 1. An example of a slider in the questionnaire. Obviously, one questionnaire contains more such sliders.

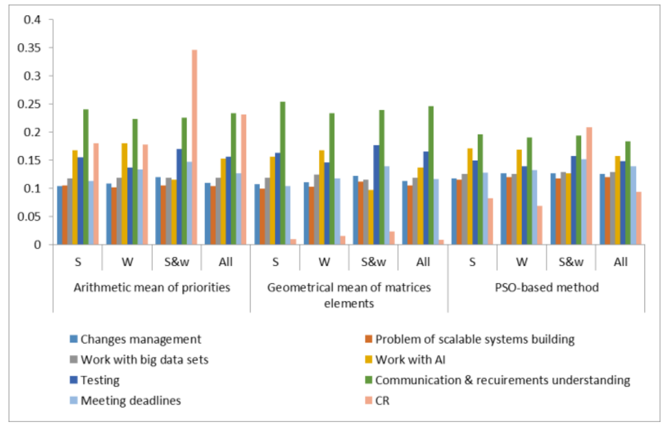

Fig. 2. The final results related to question no. 1. CR means consistency ratio. S is for students, W is for workers, while All is a summarizing result of all 102 respondents.

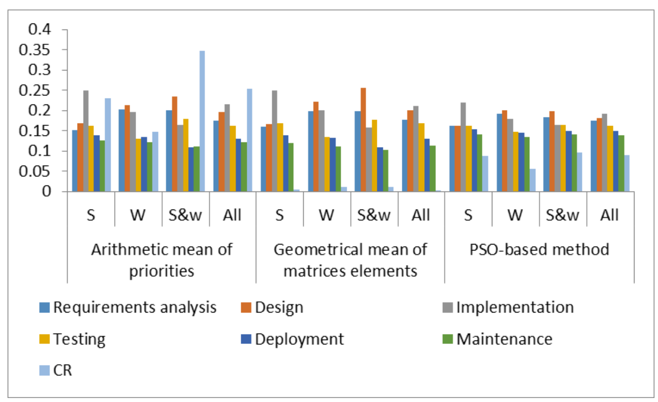

Fig. 3. The final results related to question no. 2.

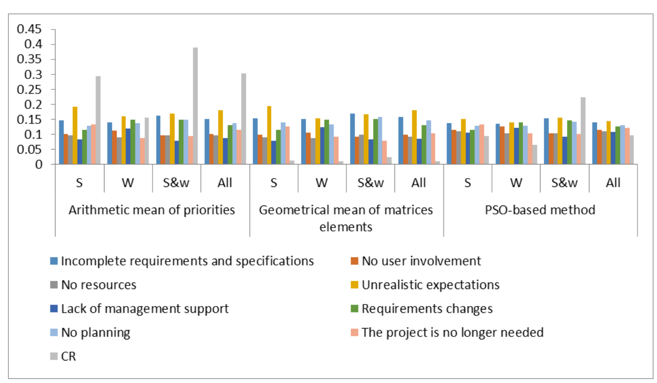

Fig. 4. The final results related to question no. 3.

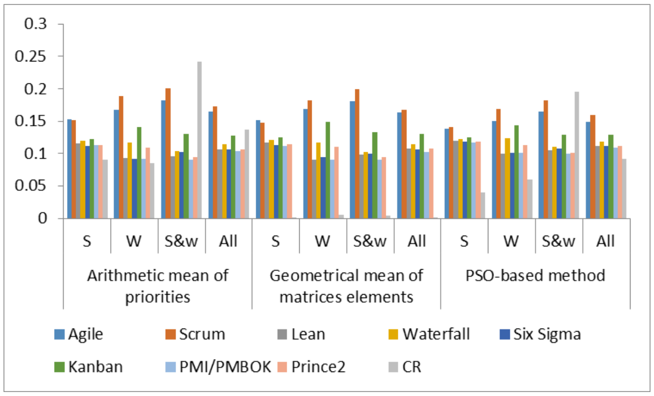

Fig. 5. The final results related to question no. 4.

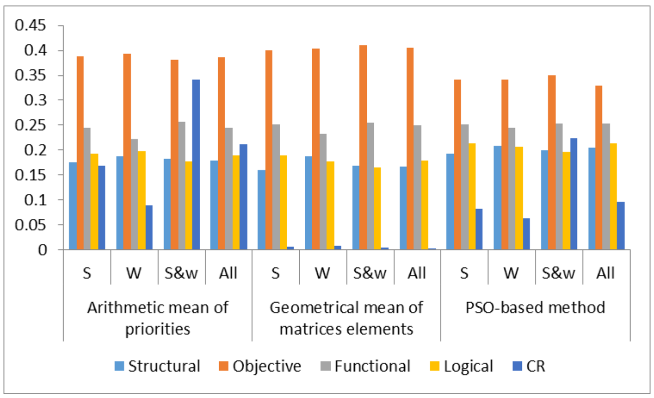

Fig. 6. The final results related to question no. 5.

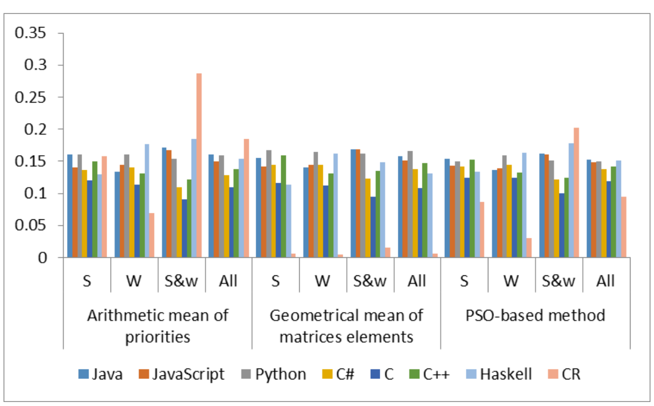

Fig. 7. The final results related to question no. 6.

shows all non-linear transformations that have emerged in the experiments. The convex shape and position of each of them below the identity transformation is noteworthy. Moreover, the experiments show one interesting property of the AHP method which is high consistency of the answers when the reciprocal matrix is built on a basis of all experts' particular reciprocal matrices using simple geometrical mean, see Figs. 2-7. Finally, it is worth to stress that the median of time of responding the whole 119 questions was about 10.5 min. This is, in our opinion, a very good result demonstrating that the AHP method enhanced in graphical tools may be a valuable option to get group decision in a short time.

TABLE I
INCONSISTENCY REDUCTION WITH RESPECT TO THE GROUPS OF RESPONDENTS

Question	Group	Difference between consistency ratio before and after the PSO
1	Students	0.1
1	Working students	0.1
1	Workers	0.41
2	Students	0.14
2	Working students	0.09
2	Workers	0.25
3	Students	0.2
3	Working students	0.09
3	Workers	0.16
4	Students	0.05
4	Working students	0.03
4	Workers	0.05
5	Students	0.09
5	Working students	0.03
5	Workers	0.12
6	Students	0.07
6	Working students	0.04
6	Workers	0.09

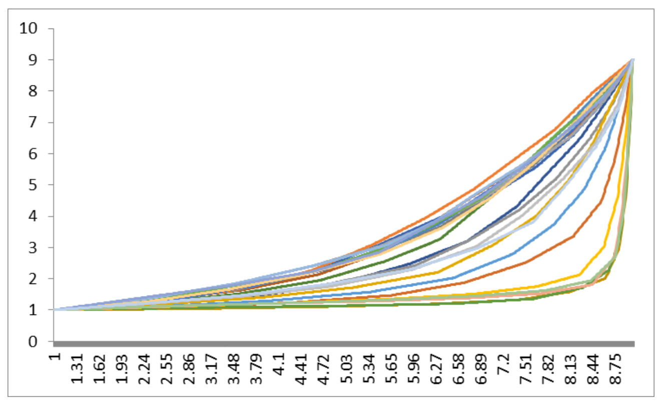

Fig. 8. All the non-linear transformations obtained in the PSO processes in the series of experiments.

From all the experiments so far we note that in the group of people studying and working the consistency ratio is not at a satisfying level. Even PSO-based reduction of expert inconsistencies is not fully satisfying. However, the idea to remove from the expert collection statements of those experts who were the most inconsistent in their assessments comes with help.

Using the FCM discussed in the previous section, we have clustered the expert's answers onto 5 clusters. FCM has returned four clusters being the same (it may happen when using FCM for multidimensional data) and one cluster being really different from these four. The answers of the experts whose opinions were most belonging to this one specific cluster (and they were less belonging to the four dominating clusters, i.e., grouping larger number of opinions) were removed from the repeated experiments. We assumed (to not increase the dimension of Fuzzy C-Mean data which is 21 for 7 questions) that the people who was really outsiders (in the sense of answering the questions) also had problems with AHP for the next five questionnaires. However, this fact was also checked empirically. Therefore, their evaluations were removed from the rest experimental repeated series. To be precise, we have removed the opinions of 7 respondents of group of people both studying and working.

From the Fig. 9 it is noticeable that the CR has been decreased significantly and it is at acceptable level. Fig. 10 demonstrates the percentage changes between the previous consistency ratios and the results obtained in the repeated experiments in the group of people working and studying at the same time. In the AHP followed by PSO case the CR coefficient was decreased by about 25%.

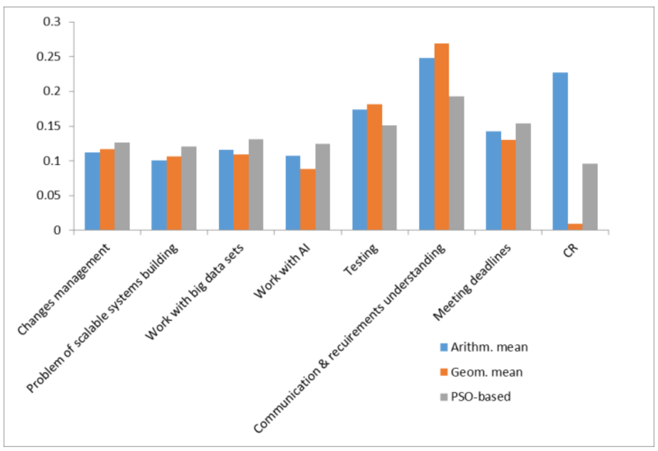

Fig. 9. Repeated results for the question no. 1

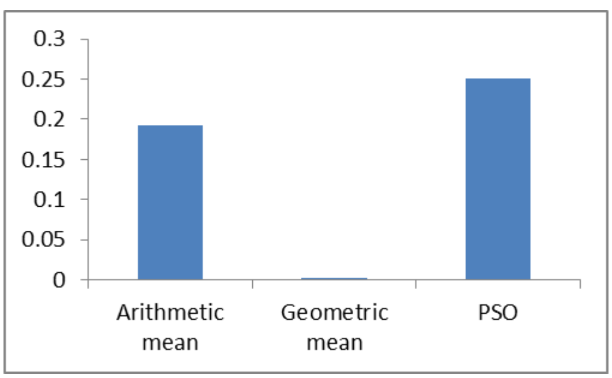

Fig. 10. Average percentage decrease of consistency ratio for three considered methods after FCM and removing votes of 7 experts from the studying and working group.

V. Conclusions and Future Work

In this work, the answers of people associated with the IT industry regarding major problems in software engineering and selected programming issues per se have been analyzed. The general opinions and knowledge of students and practitioners coming from the IT industry were tested using an innovative approach based on the Analytic Hierarchy Process and a graphic tool. The obtained results show that a survey containing 119 questions can be conducted very efficiently among a wide group of respondents (with a time median being about 10.5 min.). Research has also shown differences in seeing the main problems of software engineering by experienced IT industry employees and students. Moreover, we have presented the novel approach to improve the effectiveness of AHP, namely the Fuzzy C-Means clustering-based method of preselection of experts' opinions to build consistent reciprocal matrix of experts voices which is an input to AHP decision-making algorithm. After this preselection the efficiency of AHP measured in the level of consistency has significantly increased. Finally, using the approach presented in points (1) – (5) of Section III, we see that an application of visual components such as slider and optimization tools like PSO significantly improves the consistency of pairwise comparison algorithm.

Future research directions may be oriented towards studying if AHP is suitable for conducting skill tests. In addition, we are interested in an improving the AHP method with other non-trivial graphic components such as multi-range slider and fuzzy modeling approach (more generally, granular). Moreover, it seems interesting to introduce a noise in answering when a wide group of respondents are examined to see how such noises affect the overall result (in which case random values could replace some of the experts' responses to reduce their response time). An interesting method would be an application of anomaly detection-based algorithms to preselect totally inconsistent experts' opinions, particularly when large group of experts take part in the experiments. Finally, it is worth to investigate the question whether is there a dependency between expert's opinions consistency and his/her response time.

Acknowledgment

Funded by the National Science Centre, Poland under CHIST-ERA programme (Grant no. 2018/28/Z/ST6/00563).

References

[1] P. Karczmarek, "Selected problems of face recognition and decision-making theory," Lublin: Lublin University of Technology Publishing House, December 2018.
[2] J. C. Bezdek, R. Ehrlich, and W. Full, "FCM: The fuzzy c-means clustering algorithm," Comput. Geosci., vol. 10, no. 2–3, pp.191–203, 1984.
[3] W. S. Humphrey, "A discipline for software engineering," Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc, January 1995.
[4] J. F. Peters and W. Pedrycz, "Software engineering: An engineering approach," New York, NY, USA: John Wiley & Sons, Inc., 1998.
[5] I. Sommerville, "Software engineering," Pearson, 2015.
[6] J. Sutherland and K. Schwaber, "The Scrum guide," October 2017 [online].
[7] J. L. Brewer and K. C. Dittman, "Methods of IT projects management," Prentice Hall, 2013.
[8] G. M. Horine, "Project management absolute beginner's guide," Que Publishing, February 2017.
[9] "A guide to the Project Management Body of Knowledge (PMBOK guide)," Newton Square, PA, USA: Project Management Institute, 2018.

[10] A. Arpteg, B. Brinne, L. Crnkovic-Friis, and J. Bosch, "Software engineering challenges of deep learning," in: 2018 44th Euromicro Conference on Software Engineering and Advanced Applications (SEAA), Prague, pp. 50–59, 2018.

[11] F. Bergenti, M.-P. Gleizes, and F. Zambonelli, "Methodologies and software engineering for agent systems," USA: Springer, 2004.

[12] G. Casale, C. Chesta, P. Deussen, E. Di Nitto, P. Gouvas, S. Koussouris, V. Stankovski, A. Symeonidis, V. Vlassiou, A. Zafeiropoulos, and Z. Zhao, "Current and future challenges of software engineering for services and applications," Proced. Comput. Sci., vol. 97, 2016, pp. 34–42.

[13] V. Cosentino, J. L. Cánovas Izquierdo, and J. Cabot, "A systematic mapping study of software development with GitHub," IEEE Access, vol. 5, pp. 7173–7192, June 2017.

[14] J. C. S. Coutinho, W. L. Andrade, and P. D. L. Machado, "Requirements engineering and software testing in Agile methodologies: A systematic mapping," in: Proc. of the XXXIII Brazilian Symposium on Software Engineering, pp. 322–331, September 2019.

[15] J. Dehlinger and J. Dixon, "Mobile application software engineering: Challenges and research directions," in Workshop on Mobile Software Engineering, Vol.2, pp. 1–4, 2011.

[16] R. G. Fichman, M. Keil, and A. Tiwana, "Beyond valuation: "Options thinking" in IT project management," Calif. Rev. Manag., vol. 47, no. 2, pp. 74–96, January 2005.

[17] B. Fitzgerald and K.-J. Stol, "Continuous software engineering and beyond: trends and challenges," in Proc. 1st Int. Workshop on Rapid Continuous Software Engineering RCoSE, pp. 1–9, June 2014.

[18] D. Galan, R. Heradio, H. Vargas, I. Abad, and J. A. Cerrada, "Automated assessment of computer programming practices: The 8-years UNED experience," IEEE Access, vol. 7, pp. 130113–130119, September 2019.

[19] S. Khan, "Why IT projects fail: By understanding three key elements, internal audit can help improve the success rate of technology initiatives," Intern. Auditor, vol. 75, no. 2, pp. 16–17, April 2018.

[20] L. E. Lwakatare, A. Raj, J. Bosch, H. Holmström Olsson, and I. Crnkovic, "A taxonomy of software engineering challenges for machine learning systems: An empirical investigation," in: International Conference on Agile Software Development XP 2019: Agile Processes in Software Engineering and Extreme Programming, pp. 227–243, April 2019.

[21] G. G. Magalhães, A. L. Sartor, A. F. Lorenzon, P. O. A. Navaux, and A. C. S. Beck, "How programming languages and paradigms affect performance and energy in multithreaded applications," in: 2016 VI Brazilian Symposium on Computing Systems Engineering (SBESC), Joao Pessoa, pp. 71–78, November 2016.

[22] M. J. O'Connor, C. Nyulas, S. Tu, D. L. Buckeridge, A. Okhmatovskaia, and M. A. Musen, "Software-engineering challenges of building and deploying reusable problem solvers," Artif. Intell. Eng. Des. Anal. Manuf. 2009, vol. 23, no. 4, pp. 339—356, November 2009.

[23] W. Pedrycz, G. Succi, and A. Silliti, "Computational Intelligence and quantitative software engineering," Springer, 2016.

[24] P. L. Ramteke and M. Atique, "Software engineering challenges: A case study," in: Proceedings of the 4th National Conference; INDIACom-2010 Computing For Nation Development, pp. 1–6, 2010.

[25] R. Ryan Nelson, "IT project management: Infamous failures, classic mistakes, and best practices," MIS Q. Exec., vol. 6, no. 2, June 2007.

[26] M. Shafiq, Q. Zhang, M. A. Akbar, A. A. Khan, S. Hussain, F.-E. Amin, A. Khan, and A. A. Soofi, "Effect of project management in: requirements engineering and requirements change management processes for global software development," IEEE Access, vol. 6, pp. 25747–25763, June 2018.

[27] M. Simon, Á. Sinkovics, M. Török, T. Cséri, and Z. Porkoláb, "A practical survey on programming paradigms," in: Proc. 9th Joint Conf. Math. Comp. Sci., February 9–12, Siófok, Hungary, p. 85, February 2012.

[28] Z. Stojanovic and A. Dahanayake, "Service-oriented software system engineering: Challenges and practices," IGI Global, 2004.

[29] M. A. Terlizzi, F. de Souza Meirelles, and H. R. O. C. de Moraes, "Barriers to the use of an IT project management methodology in a large financial institution," Int. J. Proj. Manag., vol. 34, no. 3, pp. 467–479, April 2016.

[30] GitHub, "A state of the Octoverse," [online].

[31] R. Lim, "Top 10 main causes of project failure," June 2019 [online].

[32] D. Muslihat, "7 popular project management methodologies and what they're best suited for," March 2018 [online].

[33] B. Putano, "A look at 5 of the most popular programming languages of 2019," August 2019 [online].

[34] M. Symonds, "15 causes of project failure," June 2011 [online].

[35] D. Thakur, "Software engineering challenges," Ecomputer Notes [online].

[36] T. L. Saaty, "The Analytic Hierarchy Process," New York: McGraw-Hill, 1980.

[37] N. Ahmad and P. A. Laplante, "Software project management tools: Making a practical decision using AHP," in: 2006 30th Annual IEEE/NASA Software Engineering Workshop, Columbia, MD, pp. 76–84, April 2006.

[38] J. M. Reddy, S. V. A. V. Prasad, and B. V. Ramana Murthy, "An empirical analysis on McCall's quality factors of software engineering using analytic hierarchy process: A quantitative approach," Int. J. Adv. Res. Comput. Sci., vol. 8, no. 5, pp. 1644–1650, May 2017.

[39] M. Sadiq, J. Ahmed, M. Asim, A. Qureshi, and R. Suman, "More on elicitation of software requirements and prioritization using AHP," in: 2010 Int. Conf. on Data Storage and Data Engineering, Bangalore, pp. 230–234, 2010.

[40] T. L. Saaty and L. G. Vargas, "Models, methods, concepts & applications of the analytic hierarchy process," New York: Springer, October 2012.

[41] P. Karczmarek, W. Pedrycz, A. Kiersztyn, and P. Rutka, "A study in facial features saliency in face recognition: An analytic hierarchy process approach," Soft. Comput. vol. 21, no. 24, pp. 7503–7517, December 2017.

[42] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," Eur. J. Oper. Res. vol. 169, no. 1, pp. 1-–29, February 2006.

[43] J. A. Alonso and M. T. Lamata, "Consistency in the analytic hierarchy process: A new approach," Int. J. Uncertain. Fuzziness, Knowl.-Based Syst., vol. 14, no. 4, pp. 445–459, 2006.

[44] T. L. Saaty, "Fundamentals of decision making and priority theory with the analytic hierarchy process," Pittsburgh: RWS Publications, 2000.

[45] T. L. Saaty and R. S. Mariano, "Rationing energy to industries: Priorities and input-output dependence," in: The Logic of Priorities. International Series in Management Science/Operations Research, Dordrecht: Springer, pp. 182–192, 1982.

[46] E. Forman and K. Peniwati, "Aggregating individual judgments and priorities with the analytic hierarchy process," Eur. J. Oper. Res. vol. 108, np. 1, pp. 165—169, July 1988.

[47] P. Karczmarek, A. Kiersztyn, and W. Pedrycz, "An application of graphic tools and analytic hierarchy process to the description of biometric features," in L. Rutkowski et al. (Eds.) Artificial Intelligence and Soft Computing. LNCS 10842, pp. 137–147, May 2018.

[48] J. F. Kennedy, R. C. Eberhart, and Y. Shi, "Swarm intelligence," San Diego: Academic Press, 2001.

[49] R. Winkler, F. Klawonn, and R. Kruse, "Fuzzy c-means in high dimensional spaces," Int. J. Fuzzy Syst. Appl., vol. 1, no. 1, pp. 1–16, January 2011.

[50] www.interankiety.pl [online].