QPI 2020, volume 2, pp. 180-187

PRO-QUALITY CHOICE A MACHINE BY USING ORDERED FUZZY NUMBERS MODEL

doi: 10.2478/cqpi-2020-0020
Date of submission of the article to the Editor: 25/05/2020
Date of acceptance of the article by the Editor: 31/07/2020

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Abstract: Meeting the required quality level of products taking into account customer requirements is the essence of thriving enterprises. In this context, it is necessary to make decisions that take into account mentioned the quality level but also the cost aspect relevant to both customer and producer. It was concluded that it is possible to make analyse in which connected the quality level with the cost aspect will condition the make the best choice. Therefore, the aim of work was to propose the pro-quality method of choice by using the ordered fuzzy numbers connected with cost-quality analysis (AKJ). The subject of the study were machines used in pad printing technique, so-called pad print, which choice resulted from their problematic choice to specific and often variable working conditions. As part of the method by using ordered fuzzy numbers, using the Fuzzy TOPSIS method (The Technique for Order of Preference by Similarity to Ideal Solution) the most favorable machine by quality was determined. Subsequently, a pro-quality machine choice was made, and this choice combined the obtained quality level with the purchase cost through the use of cost-quality analysis. The proposed method is some kind of new approach to making the best decision, where the aspect of quality with the cost was connected. Therefore, the proposed method can be used to solve different types of decision problems in production and services enterprises.

Keywords: production engineering, mechanical engineering, Fuzzy TOPSIS, pro-quality choice, ordered fuzzy numbers

1. INTRODUCTION

Customers' requirements regarding the quality of products cause that producers try to adapt production so that it is effective and profitable not only in terms of quality but also financially (Pacana et al., 2019). As part of these actions, the important meaning has the effectiveness of decision process, which skillful made with using adequate selected decision methods can be key stage of enterprise actions (Siwiec et al. 2020; Xu and Zhang, 2013). In the context of making decisions, the effective method is the TOPSIS method (The Technique for Order of Preference by Similarity to Ideal Solution), which is the multi-criteria method to identify the possible solutions of the alternatives set, and

also to choose the so-called the ideal benefit solution and ideal negative solution (Buyukozkan and Cifci, 2012). The element which stands the TOPSIS method from other decision methods is the possibility of calculating the relative distance from the best solution, which is the so-called pattern (ideal) and distance from the worst solution, which is anti-pattern (anti-ideal) (Rudnik and Kacprzak, 2015). It is assumed that selected alternative should have the shortest distance from an ideal solution, and the longest distance from an imperfect solution (Sun, 2010). Additionally, the TOPSIS method is one of the most popular decision method, which in order to increase its precision as part of including incomplete or inaccurate information (Dagdeviren et al., 2019) was expanded about the analyze in a fuzzy environment, i.e. Fuzzy TOPSIS (Boran et al., 2009), in which the ordered fuzzy numbers are used (Rudnik and Kacprzak, 2015; Wang and Chang, 2007). In this method, it is possible to make an assessment of qualitative and quantitative criteria (Wang and Lee, 2010), but not implemented in it the actual purchase cost. Therefore, it was concluded that as part of pro-quality choice it is important to connect the FTOPSIS method with method which allows to make choice with simultaneous included the quality and cost of purchase. This method is a cost-quality analysis (AKJ) in which it is possible to implement the value of quality level and next connected this level with the cost of purchase, which allows to possibility the to make an effective pro-quality choice (Siwiec et al., 2019).
Therefore, the aim of work was to propose the pro-quality method of choice by using the ordered fuzzy numbers connected with cost-quality analysis (AKJ). The proposed method of combined directed fuzzy numbers and cost-quality analysis was proposed in an enterprise located in Podkarpacie printing using the pad printing technique. In the enterprise the pad print machine was used (six-color pneumatic inkwell with closed inkwell). The pad print machine about pneumatic drive required a compressor with adequate power, which contributed to the arduous work caused by the noise of the machine, as well as a reduction in the quality of printing. Additionally, the pneumatic pad print machine was characterized among other lack of possibilities to stop the move at any time and lack of possibilities print one once above and once below of product. Therefore, to make more effectiveness of the print process of the pad printing technique and as the same achieve a higher level of services, it was made the decision about potential buy the other type of pad print machine. The choice of pad print machine was made from machines with the electromechanical drive, which was resulted from the individual needs of a manager of the enterprise, who was based on his own knowledge and experience. To precise the best choice in term of pro-quality (i.e. including the quality and cost) the mentioned technique connected methods of Fuzzy TOPSIS and AKJ was used.

2. METHOD

The method of supporting the pro-quality choice of machine was connected methods, i.e. Fuzzy TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) and cost-quality analysis (AKJ), which are the mathematical methods, supporting the make decision. The choice of methods was conditioned their effectiveness in making the best choice, and their adequate to integrated with other techniques (Buyukozkan and Cifci, 2012; Siwiec, 2020). The proposed method was shown in 12 stages.

Stage 1. Goal setting

The first stage is the goal-setting of application of the proposed method, and in this case, the goal was to make the pro-quality choice, where this choice included at the same time the quality level and cost of purchase.

Stage 2. Selection of criteria and alternatives

The second stage is to select the criteria (criteria for assessment) and a set of alternatives (possible solutions) according to which the decision problem will be analyzed. The choice of criteria and alternatives is making by the team of experts, in which the number of criteria and number of alternative should be equal 7 ± 2, which follows from Miller's psychological framework in making effective pair-wise comparisons (Mu and Pereyra-Rojas, 2017; Suner, 2012).

Stage 3. Assessment of criteria and alternatives

The third stage is assessment of criteria and alternatives by preferred by Chen in TOPSIS the fuzzy preference scale (Wang and Elhag, 2006). The assessment is made by a team of experts, the same one who selected the criteria and alternatives in stage 2. Therefore, having the team of expert consisting of K members, the fuzzy assessment of member k^x for alternative A_i in terms of criterion C_j is as (1) (Wang and Elhag, 2006):

$$\tilde{x}_{ij}^{k} = \left(a_{ij}^{k}, b_{ij}^{k}, c_{ij}^{k}\right) \tag{1}$$

where the weight of criterion C_j is (2) (Wang and Elhag, 2006):

$$\widetilde{w}_{j}^{k} = \left(w_{j1}^{k}, w_{j2}^{k}, w_{j3}^{k}\right) \tag{2}$$

After made assessments and weights by each member of team experts is proceed to the next step.

Stage 4. Calculate the aggregate fuzzy assessments for criteria and alternatives

The fourth stage is calculating the aggregate fuzzy numbers, where the fuzzy number (1) for the alternative i^x and criterium j^x has the formula (3) (Wang and Elhag, 2006):

$$a_{ij} = min_k\{a_{ij}^{k}\}, \qquad b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^{k}, \qquad c_{ij} = max_k\{c_{ij}^{k}\} \tag{3}$$

In turns of the fuzzy weight (2) for criterion C_j is calculated from formula (4) (Wang and Elhag, 2006):

$$w_{j1} = min_k\{w_{j1}^{k}\}, \qquad w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{j2}^{k}, \qquad w_{j3} = max_k\{w_{j3}^{k}\} \tag{4}$$

After calculating the values of weights and assessments it is necessary to make the next stage.

Stage 5. Calculate the normalized matrix of fuzzy decision

In the fifth stage is calculated the normalized matrix of fuzzy decision $\tilde{R} = \left[\tilde{r}_{ij}\right]$, (5-6) (Wang and Elhag, 2006):

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), and\ c_j^* = max_i\{c_{ij}\} - benefit\ criteria \tag{5}$$

or

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), and\ c_j^- = min_i\{a_{ij}\} - cost\ criteria \tag{6}$$

where:

benefit criteria are criteria generate the profit, where them more is better, cost criteria are criteria generate the loss, where them less is better.

Stage 6. Calculate the weighted, normalized matrix of fuzzy decision

The sixth stage is calculated so-called weighted normalized matrix of fuzzy decision having the form (7) (Wang and Elhag, 2006):

$$\tilde{V} = (\tilde{v}_{ij}), where\ \tilde{v}_{ij} = \tilde{r}_{ij} \times w_j \quad (7)$$

Stage 7. Calculate Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS)

The seventh stage for FPIS is realized by using the formula (8) (Wang and Elhag, 2006):

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*), where\ \tilde{v}_j^* = max_i\{v_{ij3}\} \quad (8)$$

while for FNIS by using the formula (9) (Wang and Elhag, 2006):

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-), where\ \tilde{v}_j^- = min_i\{v_{ij1}\} \quad (9)$$

After calculated FPIS and FNIS it is necessary to make the next stage.

Stage 8. Calculate the distance

In stage eight is calculated the distance from each of alternatives to FPI and FNIS by the formula (10) (Wang and Elhag, 2006):

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), \qquad d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad (10)$$

where two triangular fuzzy numbers, i. e.: $\tilde{x} = (a_1, b_1, c_1), \tilde{y} = (a_2, b_2, c_2)$, then (11) (Wang and Elhag, 2006):

$$(\tilde{x}, \tilde{y}) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \quad (11)$$

After calculating all distances for each of the alternatives A_i to FPI and FNIS it is necessary to go to the next step.

Step 9. Calculate the proximity factor CC_i for each alternative

The nine step is realized with using the formula (12) (Wang and Elhag, 2006):

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \quad (12)$$

The calculation of proximity factors allows you to make the best selection, as described in the next step.

Stage 10. The choice the best alternative in terms of quality

In the tenth stage, it is necessary to order the proximity factors for each alternative from maximum to minimum, where the alternative with the maximum proximity factor is the best choice in terms of the level of quality (Wang and Elhag, 2006). In order to make the choice in terms of cost-quality, it is necessary to make next steps of the method.

Stage 11. Calculation of cost-quality indicators

Stage eleven should be implemented according to the method of cost-quality analysis (AKJ) which is shown in the literature of subject (for example Siwiec et al., 2019; Siwiec et al., 2020).

Stage 12. The choice the best alternative in terms of cost-quality

In the twelfth stage, it is necessary to make the pro-quality choice (i.e. cost-quality), which means according to the AKJ method idea the choice alternative with the maximum value of R_d indication.

3. RESULTS

The aim of applying the proposed method was to make a pro-quality choice of the machine by using the ordered fuzzy numbers connected with cost-quality analysis (AKJ).

This choice included the quality aspect (satisfaction of client and producer) and aspect of cost (purchase cost). An analysis of five criteria was made, which for needs of analyse was marked as A1 - inkwell type (o - open, c - closed), A2 - maximum number of color, A3 - maximum size of print, A4 - maximum size of matrix, A5 - maximum downforce. Next, the six alternatives were chosen (i.e. the types of pad print machine), i. e.: Teca-Print, Comec Polska Sp. z o. o., TampoexpeT and Tampoprint, which for needs of analyse were marked in arbitrary and random way M1-M6. The criteria and alternative were chosen based on experience and knowledge of the team of experts is composed of the company manager and the authors of the work (Table 1).

Table 1
The characterizing criteria the alternatives (types of machines)

Criteria	**Alternatives**					
	M1	**M2**	**M3**	**M4**	**M5**	**M6**
A1	C, O	O	C	O	C	Z, O
A2	5	6	4	1	5	6
A3	200	125	72	145	160	160
A4	220x440	150x300	350x150	160x350	180x360	580x350
A5	15000	3000	1300	2500	8000	6000

Next, the members of the team were assessment the criteria and alternatives by preferred by Chen in TOPSIS the fuzzy preference scale (Wang and Elhag, 2006). After assigning grades and weights by each of member of the expert team the aggregate fuzzy assessment for criteria and alternative and also the weights these criteria were calculated (Table 2).

Table 2
Aggregate fuzzy assessment

		Criteria														
		A1			**A2**			**A3**			**A4**			**A5**		
Weight		**1,0**	**4,3**	**7,0**	**4,0**	**6,7**	**9,0**	**5,0**	**8,7**	**9,0**	**6,0**	**8,7**	**9,0**	**1,0**	**3,0**	**6,0**
alternatives	M1	7,0	9,0	9,0	5,0	8,0	9,0	7,0	9,0	9,0	5,0	7,3	9,0	1,0	1,0	3,0
	M2	1,0	1,3	4,0	2,0	4,7	7,0	1,0	2,3	6,0	1,0	1,3	4,0	6,0	8,3	9,0
	M3	4,0	6,7	9,0	6,0	8,7	9,0	1,0	3,7	7,0	1,0	3,0	5,0	1,0	3,7	7,0
	M4	1,0	1,0	4,0	1,0	1,0	3,0	3,0	5,3	8,0	1,0	3,7	6,0	7,0	9,0	9,0
	M5	4,0	6,7	9,0	5,0	8,0	9,0	5,0	7,3	9,0	3,0	5,7	9,0	1,0	2,3	5,0
	M6	7,0	9,0	9,0	2,0	4,7	7,0	5,0	7,3	9,0	7,0	9,0	9,0	1,0	3,3	7,0

Then, the normalized matrix of fuzzy decision for benefit criteria (i.e. A1, A3, A4) and cost criteria (i.e. A2 and A5) was calculated. For obtained values, the weighted, normalized matrix of the fuzzy decision was calculated, and then the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) were calculated (Table 3).

Table 3
The weighted, normalized matrix of the fuzzy decision and results FPIS and FNIS

		Criteria														
		A1			A2			A3			A4			A5		
Weight		**5,4**	**1,0**	**9,0**	**0,2**	**0,1**	**1,4**	**3,9**	**0,8**	**9,0**	**3,9**	**0,8**	**9,0**	**0,3**	**0,4**	**7,0**
alternatives	M1	0,8	0,1	4,0	0,3	0,1	3,5	0,6	0,2	6,0	0,8	0,1	4,0	0,1	0,0	1,2
	M2	3,1	0,7	9,0	0,2	0,1	1,2	0,6	0,3	7,0	0,8	0,3	5,0	0,1	0,1	7,0
	M3	0,8	0,1	4,0	0,7	0,5	7,0	1,7	0,5	8,0	0,8	0,4	6,0	0,1	0,0	1,0
	M4	3,1	0,7	9,0	0,2	0,1	1,4	2,8	0,7	9,0	2,3	0,6	9,0	0,2	0,2	7,0
	M5	5,4	1,0	9,0	0,3	0,1	3,5	2,8	0,7	9,0	5,4	1,0	9,0	0,1	0,1	7,0
	M6	5,4	1,0	9,0	0,2	0,1	1,4	3,9	0,8	9,0	3,9	0,8	9,0	0,3	0,4	7,0
FPIS		2,3	5,0	7,0	1,7	7,0	9,0	5,4	9,0	9,0	5,4	9,0	9,0	0,3	3,0	5,0
FNIS		0,3	0,6	3,1	0,6	0,9	1,8	0,8	2,3	6,0	0,8	1,3	4,0	0,1	0,3	0,7

Then, the distance from all alternatives to FPI and FNIS and the proximity factor CC_i were calculated, after which it was possible to choose the best solution in terms of quality (Table 4).

Table 4
Results of the level of quality by the Fuzzy TOPSIS

Machine	∑FPIS	∑FNIS	CC_i (i.e. q)	Ranking
M1	20,7	14,8	0,42	2
M2	23,9	3,9	0,14	6
M3	22,9	10,1	0,31	4
M4	21,6	6,8	0,24	5
M5	21,0	13,3	0,39	3
M6	20,0	15,5	0,44	1

The analyze the problem by the Fuzzy TOPSIS method it was shown, that the best choice in terms of quality was choice the machine marked M6 having the maximum proximity factor equal 0,44. Then, in order to make choice in pro-quality way, so including both the level of quality and also the cost of purchase the cost-quality analyse was made, wherein the cost of purchase the pad printing machines for the needs of test the method was estimated roughly. The results of the cost-quality analysis are shown in Table 5.

Tabela 5
The results of the cost-quality analysis

Indicator	M1	M2	M3	M4	M5	M6
q	0,42	0,14	0,31	0,24	0,39	0,44
Q	41,65	14,14	30,69	23,96	38,80	43,62
K [zł]	40000,00	25000,00	30000,00	20000,00	40000,00	30000,00
c_k	960,42	1767,79	977,51	834,57	1031,01	687,72
k	0,00	0,75	0,50	1,00	0,00	0,50
E	0,00	5,30	1,63	4,17	0,00	1,15
c	0,75	0,00	0,73	0,86	0,68	1,00
d	0,00	0,91	0,69	0,88	0,00	0,56
R_e	2,27	5,30	5,75	8,97	2,08	6,38
R_t	0,32	0,37	0,48	0,54	0,30	0,55

R_d	1,30	2,83	3,11	4,76	1,19	3,46
Ranking	5	4	3	1	6	2

Simultaneous including the level of quality and the cost of purchase the pad printing machines simultaneous the best choice was the pad printing machine which was marked M4 and had the maximum value of R_d indicator equal 4,76.

4. CONCLUSION

Achieving the level of product quality required by customers is still a challenge, where it is important to take into account the cost aspect as part of enterprise efficiency. Therefore, the aim of work was to propose the pro-quality method of choice by using the ordered fuzzy numbers connected with cost-quality analysis (AKJ). The analysis was made for needs the enterprise located in Podkarpacie in which the printing was made using the pad printing technique. Therefore, the subject of the study was the pad print machines used in pad printing technique, which choice resulted from their problematic choice to specific and often variable working conditions. The five criteria were analysed, i.e.: inkwell type, maximum number of color, maximum size of print, maximum size of matrix, maximum downforce. Next, the six alternatives were chosen (i.e. the types of pad print machine), i. e.: Teca-Print, Comec Polska Sp. z o. o., TampoexpeT and Tampoprint, which for needs of analyse were marked in arbitrary and random way M1-M6. As part of the ordered fuzzy numbers model, using the Fuzzy TOPSIS method (The Technique for Order of Preference by Similarity to Ideal Solution) the best machine (i.e. ideal solution) in terms of quality was identified, and this machine was pad print machine M6 (Q=43,62). In order to include the cost of the machine the cost-quality analysis was made (AKJ). Therefore, then was connected the obtained level of quality with the cost of purchase as part of AKJ, after that, it was shown that the best choice is machine conventionally marked M4, which indicator R_d was equal 4,76. Additionally, it was shown that not always the highest quality and the highest cost is guarantee of the best choice because the quality of M4 machine was in fifth place and was equal Q=23,96. The proposed method is some kind of new approach to making the best decision, where the aspect of quality with the cost was connected. Therefore, the proposed method can be used to solve different types of decision problems in production and services enterprises.

REFERENCES

Boran, F.E., Genc, S., Kurt, M., Akay, D., 2009. *A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method,* Expert Systems with Applications, 36, 8, 11363-11368, DOI: https://doi.org/10.1016/j.eswa.2009.03.039

Buyukozkan, G., Cifci, G., 2012. *A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers*, Expert Systems with Applications, 39, 3, 3000-3011, DOI: https://doi.org/10.1016/j.eswa.2011.08.162

Dagdeviren, M., Yavuz, S., Kilinc, N., 2009. *Weapon selection using the AHP and TOPSIS methods under fuzzy environment,* Expert Systems with Applications, 36, 4, 8143-8151, DOI: https://doi.org/10.1016/j.eswa.2008.10.016

Mu, E., Pereyra-Rojas, M., 2017. *Practical Decision Making. SpringerBriefs in Operations Research*, Appendix A: Practical Questions Related to AHP Modeling, 105-106, DOI: 10.1007/978-3-319-33861-3

Nadaban, S., Dzitac, S., Dzitac, I., 2016. *Fuzzy TOPSIS: A General View*, Procedia Computer Science, 91, 823-831, DOI: 10.1016/j.procs.2016.07.088

Pacana, A., Siwiec, D., Bednárová, L. 2019. *Analysis of the incompatibility of the product with fluorescent method,* Metalurgija, 58(3-4), 337-340.

Rudnik, K., Kacprzak, D., 2015. *Rozmyta metoda TOPSIS wykorzystują skierowane liczby rozmyte,* PTZP, 958-986.

Siwiec, D., Bednárowá, L., Pacana, A. 2020. *Metoda doboru penetrantów dla przemysłowych badań nieniszczących,* Przemysł Chemiczny, 99(5), 771-773, DOI: 10.15199/62.2020.5.18

Siwiec, D., Bednárowá, L., Pacana, A., Zawada, M., Rusko, M. 2019. *Wspomaganie decyzji w procesie doboru penetrantów fluorescencyjnych do przemysłowych badań nieniszczących*, Przemysł Chemiczny, 98(10), 1594-1596, DOI: 10.15199/62.2019.10.12

Sun, C.C., 2010. *A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods,* Expert Systems with Applications, 37, 12, 7745-7754, DOI: https://doi.org/10.1016/j.eswa.2010.04.066

Suner, A., Celikoglu, C., Dicle, O., Sokmen, S., 2012. *Sequential decision tree using the analytic hierarchy process for decision support in rectal cancer.* Artjfjcal Intelligence in Medicine, 1-10, DOI: http://dx.doi.org/10.1016/j.artmed.2012.05.003

Wang, T.C., Chang, T.H., 2007. *Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment*, Expert Systems with Applications, 33, 4, 870-880, DOI: https://doi.org/10.1016/j.eswa.2006.07.003

Wang, T.C., Lee, H.D., 2010. *Developing a fuzzy TOPSIS approach based on subjective weights and objective weights*, Expert Systems with Applications, 36, 5, 8980-8985, DOI: https://doi.org/10.1016/j.eswa.2008.11.035

Wang, Y.M., Elhag, T., 2006. *Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment,* Expert Systems with Applications, 31, 2, 309-319, DOI: https://doi.org/10.1016/j.eswa.2005.09.040

Xu, Z., Zhang, X., 2013. *Hesitant fuzzy multi-attribute decision making based on TOPSIS with incomplete weight information,* Knowledge-Based Systems, 52, 53-64, DOI: https://doi.org/10.1016/j.knosys.2013.05.011