Digital Transformation Technology Evaluation in a post COVID-19 World with an Integrated Fuzzy SAW-ARAS Methodology

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Abstract. *The COVID-19 pandemic has generated unfamiliar worldwide health and economic crisis and caused many results. In order to be successful in the changing world, organizations should efficiently integrate digital technologies into their digital working practices. This paper aims to present an analytical technique for evaluating the digital technologies in a post COVID-19 world. Fuzzy sets approach is used for reflecting uncertainty in the decision-making process. Fuzzy Simple Additive Weighting (SAW) technique is used to calculate critical success factors' weights and fuzzy Additive Ratio ASsessment (ARAS) technique is used to rank digital technologies. A case study is realized to show the potential of the research methodology. Finally, the conclusions and perspectives for future research are presented.*

Keywords. ARAS, Digital Transformation, MCDM, SAW, Technology Evaluation.

1 Introduction

The COVID-19 pandemic has drastically caused organizational changes and worked as a catalyst for digital transformation in many sectors (Hawash et al., 2020; Priyono et al., 2020). Companies have been forced to adopt new digital working practices and redesign their business models (Almeida et al., 2020). In this context, digital transformation can be defined as "… the journey of using digital technologies to develop new business models and strategies"(Büyüközkan & Güler, 2020). Digital technologies' capabilities and their application fields have been increasing day by day. For instance, higher education institutions are using cloud-based services allowing for on-demand access and improving their security (Insights & Innovators, 2022).

In the literature, the digital transformation subject in a post COVID-19 world has been examined in various studies. (Hawash et al., 2020) investigated the impact of the pandemic on oil and gas sector while (Agostino et al., 2020) examined the accelerator role of the pandemic for the public service delivery. (Priyono et al., 2020) aimed to determine paths of digital transformation for small and medium sized enterprises. (Almeida et al., 2020; Hai et al., 2021; Kutnjak, 2021) investigated the challenges and opportunities of digital transformation in a post COVID-19 world. (Kruszyńska-Fischbach et al., 2021) aimed to assess e-readiness of healthcare organizations during the pandemic in Poland. (Bartsch et al., 2021) examined the role of leadership on service providers' digital transformation process during the pandemic.

In this paper, the aim is providing an analytical technique for evaluating digital technologies in a post COVID-19 world. The digital transformation of an organization is affected by a number of critical success factors. The importance degrees of these factors can be taken into consideration by using Multi-Criteria Decision-Making (MCDM) techniques. The importance degrees of the critical success factors are determined by implementing the fuzzy Simple Additive Weighting (SAW) technique. The digital technologies are ranked by applying the fuzzy Additive Ratio ASsessment (ARAS) technique.

The fuzzy sets are proposed by (Zadeh, 1965) as a class of objects with a continuum of grades of membership. In this study, fuzzy MCDM techniques are used for reflecting the uncertainty and imprecision of information. This study contributes to literature by integrating the fuzzy SAW-ARAS techniques for the digital transformation technology evaluation. The critical success factors for digital transformation are determined based on literature survey, industry reports and expert opinions. Group Decision Making (GDM) approach is preferred by advising many Decision-Makers (DMs). In this regard, subjectivity in the decision-making process is eliminated. Then, a case study about digital technology evaluation is realized with the participation of DMs to illustrate the potential employment of the presented methodology.

The organization of the paper is as follows. The next section explains the research methodology which consists of three main stages. In the third section, a case study of the research methodology is presented. In the last section, the concluding remarks and perspectives for future studies are summarized.

2 Research Methodology

The methodology is provided in Figure 1. which contains three stages. In the first stage, the critical success factors in the evaluation model and the digital technology alternatives are determined with the help of the literature review and the opinions of the experts. The factors' weights are calculated in the second stage by implementing fuzzy SAW method. In the last stage, the alternatives are ranked by using fuzzy ARAS method.

Figure 1. The stages of the research methodology

2.1. The Critical Success Factors for Digital Transformation

The continuing growth in digital technologies is important as it makes permanent competitive advantage for those organizations who implement and adopt it. To be successful in the digital transformation process, many aspects should be considered. Therefore, in this study, the critical success factors on digital transformation are determined based on experts' views, literature survey and industry reports' investigation. These factors are listed in Table 1.

Table 1. The critical success factors

Critical Success Factors	References
CSF1. Fast decision-making	(Third Stage Consulting Group, 2021) (Kruszyńska-Fischbach et al., 2021)
CSF2. Internal ownership and learning	(Third Stage Consulting Group, 2021) (Kruszyńska-Fischbach et al., 2021)
CSF3. Business process management	(Third Stage Consulting Group, 2021) (Kruszyńska-Fischbach et al., 2021) (Kutnjak, 2021)
CSF4. Flexibility	(Third Stage Consulting Group, 2021) (Kruszyńska-Fischbach et al., 2021)
CSF5. Risk mitigation	(Third Stage Consulting Group, 2021) (Kutnjak, 2021)
CSF6. Human capital management	(Third Stage Consulting Group, 2021) (Kruszyńska-Fischbach et al., 2021)
CSF7. Environmental sustainability	(Arora, 2021) (Hawash et al., 2020)
CSF8. Customer retention and growth	(Arora, 2021) (Hawash et al., 2020)
CSF9. Operational resilience	(Arora, 2021) (Kruszyńska-Fischbach et al., 2021) (Kutnjak, 2021)
CSF10. Workforce retention/reskilling	(Arora, 2021) (Kruszyńska-Fischbach et al., 2021) (Kutnjak, 2021)

2.2. Fuzzy SAW Method

Step 1. The views of the DMs' are collected. The decision matrix with fuzzy linguistic terms provided in Table 2 is constructed. Please refer to (Chou et al., 2008) for details of the method.

Table 2. The fuzzy linguistic scale (Beg & Rashid, 2013)

Linguistic term	Abb.	Fuzzy Numbers
Perfect	P	(0.83,1,1)
Very High	VH	(0.67,0.83,1)
High	H	(0.5,0.67,0.83)
Medium	M	(0.33,0.5,0.67)
Low	L	(0.17,0.33,0.5)
Very Low	VL	(0,0.17,0.33)
None	N	(0,0,0.17)

Step 2. The linguistic terms are transferred into fuzzy numbers as in Table 1.

Step 3. The DMs' weights are not equal, and it reflects the relevance levels of each DM. The fuzzy weights of the DMs are represented by the $\widetilde{\omega_t}$. The importance degrees of DMs (I_t) is computed as:

$$I_t = \frac{d(\widetilde{w_t})}{\sum_{t=1}^{k} d(\widetilde{w_t})}, t = 1,2,\dots,k \qquad (1)$$

In this case, $d(\widetilde{w_t})$ represents the fuzzy weight's defuzzified value.

Step 4. Aggregated fuzzy weights of C_j, $\widetilde{W_j} = (a_j, b_j, c_j, d_j)$, are computed as:

$$\widetilde{W_j} = (I_1 \otimes \widetilde{W_{j1}}) \oplus (I_2 \otimes \widetilde{W_{j2}}) \oplus \dots \oplus (I_k \otimes \widetilde{W_{k1}}) (2)$$

Here, $a_j = \sum_{t=1}^{k} I_t a_{jt}$, $b_j = \sum_{t=1}^{k} I_t b_{jt}$, $c_j = \sum_{t=1}^{k} I_t c_{jt}$, $d_j = \sum_{t=1}^{k} I_t d_{jt}$.

Step 5. The fuzzy weights are defuzzified. The defuzzified $\widetilde{W_j}$, shown as $d(\widetilde{W_j})$, is computed as:

$$d(\widetilde{W_j}) = \frac{1}{4}\left(a_j + b_j + c_j + d_j\right), where\ j = 1, 2, \dots, n \tag{3}$$

Step 6. The normalized weights (W_j) are computed as:

$$W_j = \frac{d(\widetilde{w_j})}{\sum_{j=1}^{n} d(\widetilde{w_j})}, j = 1,2,\dots,n \tag{4}$$

$\sum_{j=1}^{n} W_j = 1$. Finally, the weight vector W=($W_1, W_2, \dots, W_n$) is established.

2.3. Fuzzy ARAS Method

Step 1: The views of the DMs' are collected. The decision matrix with fuzzy linguistic terms provided in Table 2 is constructed. Please refer to (Medineckiene et al., 2015) for details of the method.

Step 2: The matrix is normalized as:

For maxima preferable values of criteria:

$$\tilde{\tilde{x}} = \frac{\widetilde{x_{ij}}}{\sum_{i=0}^{m} \widetilde{x_{ij}}} \tag{5}$$

For minima preferable values of criteria:

$$\widetilde{x_{ij}} = \frac{1}{\widetilde{x_{ij}^*}}, \qquad \tilde{\tilde{x}}_{ij} = \frac{\widetilde{x_{ij}}}{\sum_{i=0}^{m} \widetilde{x_{ij}}} \tag{6}$$

Step 3: The weighted normalized matrix is constructed as:

$$\hat{\tilde{x}}_{ij} = \tilde{\tilde{x}}_{ij} \widetilde{w}_j\ ,\ i=0,1,\dots,m \tag{7}$$

w_j is the j^{th} criterion's weight and:

$$\sum_{j=1}^{n} w_j = 1 \tag{8}$$

Step 4: The optimality function value of i^{th} alternative is determined as:

$$\widetilde{S}_i = \sum_{j=1}^{n} \hat{\tilde{x}}_{ij}\ ,\ i=0,1,\dots,m \tag{9}$$

Step 5: In order to find the result, the center of area technique is applied as:

$$S_i = 1/3(S_{i\alpha} + S_{i\beta} + S_{i\gamma}) \tag{10}$$

Step 6: Alternatives' utility degree is determined as:

$$K_i = \frac{S_i}{S_0}\ ,\ i=0,1,\dots,m \tag{11}$$

where S_0 is the value of most ideal criterion.

3 Case Study

As a result of the digital transformation, utilization of new digital technologies has emerged as an enabler of the development of new products and services over the past two decades (Insights & Innovators, 2022). Companies can benefit from a variety of digital technologies according to their business needs. Therefore, it is important to evaluate the digital technologies and select the most appropriate one.

In order to evaluate the digital technologies regarding their impacts on critical success factors, different technologies are determined. Then, these technologies are evaluated by using the proposed fuzzy SAW- ARAS techniques. The critical success factors were summarized in Table 1. Digital technology alternatives are selected grounded on industry reports. The alternatives can be summarized as the following (Insights & Innovators, 2022):

- **A1. Mobile Wireless Technology:** This technology's indirect economic impact is estimated to be widespread and touch almost all sectors as the technology is implemented and used to solve productivity problems.
- **A2. Cloud Computing & Distributed Infrastructure:** This technology can provide important cost declines for organizations, data integrity and recovery, minimal maintenance, on demand access, and the flexibility to customized services to the needs of individual clients.
- **A3. Artificial Intelligence & Machine Learning:** This technology replicates human competencies efficiently, effectively, and cost-effectively, thus indicating a labor-saving technology.
- **A4. Robotics & Autonomous Systems**: The importance of this technology can be considered as its strong financial influence as an industrial and disrupting socioeconomic impression through various sectors.
- **A5. Quantum Computing:** Applying this technology opens the door to numerous functions that are beyond the abilities of existing computers.
- **A6. Greentech:** Emerging green technologies are expected to help companies in meeting more aggressive environmental and sustainability goals.

DMs who have experience and knowledge in digital transformation have evaluated the critical success factors by using the fuzzy linguistic terms. These fuzzy linguistic terms and their triangular fuzzy numbers were provided in Table 2. The evaluation of DMs are provided in Table 3.

Table 3. The evaluations of DMs for factors

Factors	DM1	DM2	DM3
CSF1	H	VH	H
CSF2	M	M	VH
CSF3	VH	P	P
CSF4	H	H	L
CSF5	M	L	M
CSF6	M	H	H
CSF7	VH	VH	M
CSF8	P	P	VH
CSF9	VH	M	VH
CSF10	M	H	M

The steps of fuzzy SAW technique Eqs. (1)-(4) are implemented and the critical success factors' weights are found. Table 4 displays the weights.

At the end of the fuzzy SAW application, it is possible to say that the most important critical success factor is found as "CSF3. Business process management", followed by "CSF7. Environmental sustainability" and "CSF9. Operational resilience".

Then, DMs evaluated digital technologies according to their insights by using comparative linguistic terms sets specified in Table 2. The evaluation of the first DM for alternatives is provided in Table 5. The steps of fuzzy ARAS technique Eqs. (5)-(11) are implemented and the ranking of the technologies is determined. Table 6 displays the results.

Table 4. The weights of factors

Factors	Weights	Ranking
CSF1	0.107	5
CSF2	0.090	7
CSF3	0.134	1
CSF4	0.082	8
CSF5	0.066	10
CSF6	0.090	6
CSF7	0.107	3
CSF8	0.134	1
CSF9	0.107	3
CSF10	0.082	9

Table 5. The evaluation of the first DM for alternatives

Factors	A1	A2	A3	A4	A5	A6
CSF1	H	VH	VH	M	VH	L
CSF2	H	H	VH	VH	M	VH
CSF3	VH	H	H	VH	M	M
CSF4	VH	VH	M	VH	H	H
CSF5	P	VH	H	H	P	VH
CSF6	M	H	H	VH	L	H
CSF7	VH	M	H	M	H	H
CSF8	H	VH	L	H	P	M
CSF9	P	H	VH	H	VH	VH
CSF10	H	H	VH	M	P	H

Table 6. The ranking of alternatives

Ai	$S_{i\alpha}$	$S_{i\gamma}$	$S_{i\beta}$	*Si*	*Ki*	Ranking
A0	0.168	0.198	0.248	0.204	1.000	-
A1	0.091	0.141	0.209	0.147	0.718	3
A2	0.090	0.140	0.215	0.148	0.726	2
A3	0.091	0.140	0.216	0.149	0.727	1
A4	0.088	0.137	0.211	0.145	0.711	5
A5	0.091	0.140	0.209	0.147	0.718	4
A6	0.071	0.126	0.201	0.133	0.650	6

The A3. Artificial Intelligence & Machine Learning is ranked as the first among other technologies (K3:0.727) and A2. Cloud Computing & Distributed Infrastructure (K2:0.6726) is ranked as the second.

4 Conclusion

Digital transformation in a post COVID-19 world is an interesting subject for both researchers and practitioners. According to the politicians and academics, digital transformation can be considered as a critical aspect in the progress of industries and economies in general. Digital transformation is not only an essential, it is also a chance for nations (Assar et al., 2022). Therefore, with the utilization of digital technologies many benefits can be provided for both industries and society.

Digital technologies have a potential to serve as an enabler of digital transformation for organizations. However, the most appropriate digital technology for an organization is dependent on many factors such as company size, industry and strategic goals. Therefore, in this paper, it was aimed to present a research methodology for evaluating the digital technologies. In this context, an integrated fuzzy SAW-ARAS technique is implemented. This paper contributes to the literature by integrating these techniques for digital transformation in post-pandemic world. At the end of the case study, the most important critical success factor is found as "Business process management". According to a survey conducted by (Arora, 2021) organizational change is the first challenge among executives that had recently gone through a digital transformation. Therefore, it is crucial to implement digital technologies by efficiently managing the business processes and the organizational change.

In future research, other fuzzy MCDM methods (e.g. VIKOR, TOPSIS, CODAS, EDAS) can be applied and the results of the existing methodology can be compared with its results. Further, other fuzzy set extensions (e.g. type-2 fuzzy sets, interval valued fuzzy sets, intuitionistic fuzzy sets, hesitant fuzzy sets etc.) may be chosen in future study.

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References

Agostino, D., Arnaboldi, M., & Lema, M. D. (2020). New development: COVID-19 as an accelerator of digital transformation in public service delivery. *Public Money and Management*, 1–4. https://doi.org/10.1080/09540962.2020.1764206

Almeida, F., Duarte Santos, J., & Augusto Monteiro, J. (2020). The Challenges and Opportunities in the

Digitalization of Companies in a Post-COVID-19 World. *IEEE Engineering Management Review*, *48*(3), 97–103. https://doi.org/10.1109/EMR.2020.3013206

Arora, R. (2021). 2021 Digital Transformation Assessment. In *The Manufacturer*. https://www.ibm.com/downloads/cas/MPQGMEN9

Assar, S., Rupeika-Apoga, R., Petrovska, K., & Bule, L. (2022). The Effect of Digital Orientation and Digital Capability on Digital Transformation of SMEs during the COVID-19 Pandemic. *Journal of Theoretical and Applied Electronic Commerce Research 2022, Vol. 17, Pages 669-685*, *17*(2), 669–685. https://doi.org/10.3390/JTAER17020035

Bartsch, S., Weber, E., Büttgen, M., & Huber, A. (2021). Leadership matters in crisis-induced digital transformation: how to lead service employees effectively during the COVID-19 pandemic. *Journal of Service Management*, *32*(1), 71–85. https://doi.org/10.1108/JOSM-05-2020-0160

Büyüközkan, G., & Güler, M. (2020). Analysis of companies' digital maturity by hesitant fuzzy linguistic MCDM methods. *Journal of Intelligent and Fuzzy Systems*, *38*(1), 1119–1132. https://doi.org/10.3233/JIFS-179473

Chou, S. Y., Chang, Y. H., & Shen, C. Y. (2008). A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. *European Journal of Operational Research*, *189*(1), 132–145. https://doi.org/10.1016/j.ejor.2007.05.006

Hai, T. N., Van, Q. N., & Tuyet, M. N. T. (2021). Digital transformation: Opportunities and challenges for leaders in the emerging countries in response to covid-19 pandemic. *Emerging Science Journal*, *5*(Special Issue), 21–36. https://doi.org/10.28991/esj-2021-SPER-03

Hawash, B., Abuzawayda, Y. I., Mokhtar, U. A., Yusof, Z. M., & Mukred, M. (2020). Digital Transformation in the Oil and Gas Sector during Covid-19 Pandemic. *International Journal of Management (IJM*, *11*(12), 717–724. https://doi.org/10.34218/IJM.11.12.2020.067

Insights, L., & Innovators, F. O. R. (2022). *2022 Emerging Technology Trends*.

Kruszyńska-Fischbach, A., Sysko-Romańczuk, S., Rafalik, M., Walczak, R., & Kludacz-Alessandri, M. (2021). Organizational E-Readiness for the Digital Transformation of Primary Healthcare Providers during the COVID-19 Pandemic in Poland. *Journal of Clinical Medicine 2022, Vol. 11, Page 133*, *11*(1), 133. https://doi.org/10.3390/JCM11010133

Kutnjak, A. (2021). Covid-19 Accelerates Digital Transformation in Industries: Challenges, Issues, Barriers and Problems in Transformation. *IEEE Access*, *9*, 79373–79388. https://doi.org/10.1109/ACCESS.2021.3084801

Medineckiene, M., Zavadskas, E. K., Björk, F., & Turskis, Z. (2015). Multi-criteria decision-making system for sustainable building assessment/certification. *Archives of Civil and Mechanical Engineering*, *15*(1), 11–18. https://doi.org/10.1016/j.acme.2014.09.001

Priyono, A., Moin, A., & Putri, V. N. A. O. (2020). Identifying digital transformation paths in the business model of smes during the covid-19 pandemic. *Journal of Open Innovation: Technology, Market, and Complexity*, *6*(4), 1–22. https://doi.org/10.3390/joitmc6040104

Third Stage Consulting Group. (2021). *Digital Transformation 2021 Report* (Vol. 35, Issue 4).

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X