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Digital transformation project selection using Interval Valued Type-2 Intuitionistic Fuzzy TOPSIS

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Abstract: Digital transformation necessitates fundamental changes in business processes, business models, and even cultures of the companies. DT projects provide a substantial value to the business competition and effect their market shares. In order to reach these results, digital transformation projects should be carefully analyzed and evaluated. In this paper, we focus on digital transformation project prioritization problem under multiple criteria. Just like many other technology related decisions, digital transformation problems are inherently uncertain, which leads researchers to employ the fuzzy set theory. Interval Valued Type-2 Intuitionistic Fuzzy Sets (IVT2IFS) are a relatively new extension of fuzzy sets which take into account membership and non-membership values as an interval. In this paper, we utilize Interval Valued Type-2 Intuitionistic Fuzzy TOPSIS method for a digital transformation project prioritization problem and apply the model to a real-world example.

Keywords: Digital transformation, Interval Valued Type-2 Intuitionistic Fuzzy Sets (IVT2IFS), TOPSIS, Project selection.
2020 Mathematics Subject Classification: 60-08, 62B10.

1 Introduction

Using digital technologies to generate innovation by modifying processes and businesses is called digital transformation (DT) [9]. In DT, a systematic approach should be used since the transformation process is highly complex, and different departments of the company should in involved [7]. In other words, DT aims to apply digital technologies innovatively, so that organization of a company and its operations change dramatically [4, 14] focus on the organizational change that DT can cause and state that business capabilities, inner and outer relationships, and business processes can be redefined as a result of DT projects. Lucas et al. [13] also emphasize that DT can go beyond traditional business processes improvements and it can facilitate as a tool to create new types of organizations, by revising value creation, customer relationships, and organizational culture. As a result of emerging technologies, companies face different DT project alternatives which have different investments and returns. Literature re-view show that criteria such as budget, energy savings, effects on competitive-ness, strategic value are used to select DT projects. In order to reach robust results, DT projects selection must be modeled as a multi-criteria decision-making problem, and various decision criteria should be involved in the decision-making process.

Multi-criteria decision making using exact values in the decision matrix is rarely realistic. It generally falls short of considering the uncertainty in human perceptions and thoughts. Fuzzy set theory offers the advantage of adding this uncertainty to the evaluation process by digitizing it with appropriate techniques. The literature provides various applications of fuzzy sets [10, 12, 16, 17]. Interval Valued Type-2 Intuitionistic Fuzzy Sets (IVT2IFS) are an extension of traditional fuzzy sets which allow decision makers to assign membership and non-membership values as an interval. In this study, a multi-criteria decision making model for digital transformation project evaluation is developed. IVT2IF TOPSIS method is used to solve the problem in a real world case study.

The structure of the paper is as follows: Section 2 presents a brief literature review on DT selection and lists the criteria. Section 3 explains IVT2IF TOPSIS method while Section 4 gives the solution of the real-world application the final section gives discussions and concludes the paper.

2 DT project selection

Over the last decade, organizations are subject to immense change as a result of advances in technology such internet of things, data analytics, and artificial intelligence. This change is entitled DT and it is defined as the process of using digital technologies to create innovation in business processes and customer experience. Wade [20] reports that the new advancements in technology such as mobile applications, social media, IoT, business analytics, artificial intelligence, and share economies are the leading drivers for DT. Whereas, only using these new advancements is not the key to a successful DT. Developing the necessary capabilities, culture, strategies and human resource are the real drivers behind a successful DT project [11]. Besides these key elements, customer attitudes and expectations, the changing trend towards digitalization on the industry, the industry completion level, and the regulatory changes are the factors that force companies towards DT [2]. On the other hand, various barriers limit the success and adaptation of DT projects. Chen et al. [3] conducted an interview based approach for defining the barriers to DT. According to this study, there are four barriers, namely, absence of funding, absence of digital capability, absence of human resources, and technical barriers.

The literature also provides some insight into the criteria to be used for DT project selection. The criteria and associated references are as follows:

Budget: This criterion refers to the economic perspective of the project. Budget criterion has been used in the project select literature [18, 19]. Like other projects, DT projects need initial investment and the amount of required investment affects the decision.

Materials savings: DT projects may also create materials savings because of effective process design. As a result of rising productivity and reductions in waste, It's estimated that only mine digitalization could save $370 billion per year by 2025 [5].

Effects on competitiveness: Competitiveness indicates the capability and performance of an institution, with respect to the performance of other institutions. In the literature, alternative projects' effect on the competitiveness of the company is proposed as an important criterion [18].

Labor savings: One of the most obvious expected benefits of DT projects is labor savings [6]. As the process is digitized the number of employees is expected to decrease. As a result, labor savings affect the return on investment of projects so they can be used as a criterion for digital transformation project selection [8].

Improved decision making: Since DT projects digitalize the process, data about processes can be collected and visibility throughout the company increases, and managerial decision-making can be empowered. Depending on the nature of the projects, the effect of each DT project can be different. Under this criterion, the DT projects are evaluated based on their effects on the decision-making process [18].

3 Interval Valued Type-2 Intuitionistic Fuzzy TOPSIS

Traditional Fuzzy sets are based on the membership value of an element. Later, extensions of fuzzy sets have been proposed to define information in better ways. Type-2 Intuitionistic Fuzzy sets are one of these extensions, however, it uses membership, non-membership and hesitancy parameters when defining a set element. In one perspective it is similar to intuitionistic fuzzy sets (IFS) but allows researchers to assign membership, and non-membership degrees in a wider area when compared with IFS [1]. In Type-2 Intuitionistic Fuzzy sets (T2IFS), squared sum of a membership degree and a non-membership degree must be equal to or less than one. Let ∪ be a universe of discourse. A T2IFS $\tilde{P}$ an can be defined as,

$$\tilde{P} = \{x, P(\mu_P(x), v_P(x)) | x \in X\} \tag{1}$$

where $\mu_P : X \to [0,1]$ shows the membership degree and $v_P : X \to [0, 1]$ shows the non-membership degree. Interval Valued Type-2 Intuitionistic Fuzzy Set (IVT2IFS) can be represented by $\tilde{P} = \{\langle x, [\mu_{\tilde{P}}^-, \mu_{\tilde{P}}^+], [v_{\tilde{P}}^-, v_{\tilde{\tilde{P}}}^+]\rangle | x \in X\}$. IVT2IFS, membership and non-membership values are assigned as intervals. TOPSIS method has been extended by using IVT2IFS. The steps of IVT2IF TOPSIS is given as follows [15].

Step 1. By using the linguistic scale given in Table 1 decision matrix $[\tilde{Y}_P]$ involving IVT2IFSs are constructed as in Eq. (2) and weights of the criteria $\widetilde{W}_P$ are determined.

Table 1. IVT2IF scale

Linguistic Terms	Corresponding IVT2IFS
Certainly Poor (CP)	⟨[0.00, 0.00], [0.90, 1.00]⟩
Very Poor (VP)	⟨[0.10, 0.20], [0.80, 0.90]⟩
Poor (P)	⟨[0.20, 0.35], [0.65, 0.80]⟩
Medium Poor (MP)	⟨[0.35, 0.45], [0.55, 0.65]⟩
Medium/Fair (F)	⟨[0.45, 0.55], [0.45, 0.55]⟩
Medium Good (MG)	⟨[0.55, 0.65], [0.35, 0.45]⟩
Good (G)	⟨[0.65, 0.80], [0.20, 0.35]⟩
Very Good (VG)	⟨[0.80, 0.90], [0.10, 0.20]⟩
Certainly Good (CG)	⟨[0.90, 1.00], [0.00, 0.00]⟩

$$\tilde{Y}_P = \begin{array}{c} x_1 \\ \vdots \\ x_m \end{array} \begin{bmatrix} P([\mu_{11}^-, \mu_{11}^+], [v_{11}^-, v_{11}^+]) & \cdots & P([\mu_{1n}^-, \mu_{1n}^+], [v_{1n}^-, v_{1n}^+]) \\ \vdots & \ddots & \vdots \\ P([\mu_{m1}^-, \mu_{m1}^+], [v_{m1}^-, v_{m1}^+]) & \cdots & P([\mu_{mn}^-, \mu_{mn}^+], [v_{mn}^-, v_{mn}^+]) \end{bmatrix} \tag{2}$$

where n denotes the number of criteria $(j = 1, \dots, n)$ and m denotes the number of alternatives $(i = 1, \dots, m)$.

Step 2. In case of multiple decision makers, Expected IVT2IF judgments are formed for each decision maker k by using Eq. (3). The optimism level of the decision makers are defined with a parameter $\lambda \epsilon [0,1] \epsilon$ where the number bigger than 0.5 denotes an optimistic decision maker whereas numbers lower than 0.5 denotes a pessimistic decision maker.

$$\begin{aligned} \mu_{ij}^k &= (1 - \lambda_k)\mu_{ij}^{k-} + \lambda_k \mu_{ij}^{k+} \\ v_{ij}^k &= \lambda_k \mu_{ij}^{k-} + (1 - \lambda_k)\mu_{ij}^{k+} \end{aligned} \tag{3}$$

Step 3. Aggregated decision matrix $\tilde{Y}_{agg} = (\mu_{ij}, v_{ij}, \pi_{ij})_{m \times n}$ is obtained based on expected IVT2IF judgments as in Eq.(4) where φ_k is the relative weight of the decision maker k.

$$\tilde{Y}_{agg} = \left(\sqrt{1 - \prod_{k=1}^{K} \left(1 - ({\mu_{ij}}^k)^2\right)^{\varphi_k}}, \prod_{k=1}^{K} \left(v_{ij}^k\right)^{\varphi_k} \right) \tag{4}$$

Step 4. Positive Ideal Solution ($\widetilde{PIS}$) and, Negative Ideal Solution ($\widetilde{NIS}$) are defined by using the maximum and minimum scores of alternatives as in Eq. (5) and Eqs. (6–7).

$$Score(P(x_1)) = \mu_{x_1}^2 - v_{x_1}^2 \tag{5}$$

$$\left\{\widetilde{PIS} = P_j, \max_i Score(P_j(x_1))\right\}, j = 1, \dots, n \tag{6}$$

$$\left\{\widetilde{NIS} = P_j, \max_i Score(P_j(x_1))\right\}, j = 1, \dots, n \tag{7}$$

Step 5. The distances from each alternative to the PIS and the NIS are calculated by using Eq. (8) and (9).

$$D^+\left(x_i, \widetilde{PIS}\right) = \frac{1}{2}\sum_{j=1}^{n} w_j \times \left(\left|\mu_{ij}^2 - ({\mu_j}^+)^2\right| + \left|v_{ij}^2 - ({v_j}^+)^2\right| + \left|\pi_{ij}^2 - ({\pi_j}^+)^2\right|\right) \tag{8}$$

$$D^-\left(x_i, \widetilde{NIS}\right) = \frac{1}{2}\sum_{j=1}^{n} w_j \times \left(\left|\mu_{ij}^2 - ({\mu_j}^-)^2\right| + \left|v_{ij}^2 - ({v_j}^-)^2\right| + \left|\pi_{ij}^2 - ({\pi_j}^-)^2\right|\right) \tag{9}$$

Step 6. Relative degree of closeness values $U(x_i)$ are obtained by using Eq. (10).

$$U(x_i) = \frac{D^-(x_i, \widetilde{NIS})}{D^-(x_i, \widetilde{NIS}) + D^+(x_i, \widetilde{PIS})} \tag{10}$$

Step 7. The alternatives are ranked by using $U(x_i)$ values. Larger $U(x_i)$ indicate a better alternative.

4 Numeric application

In this study, a selection problem among five digital transformation projects (DTP1, DTP2, DTP3, DTP4, and DTP5) is handled by considering five criteria, which are “C1: Budget”, “C2: Labor savings”, “C3: Material savings”, “C4: Effects on competitiveness”, and “C5: Improved decision making”. The *Budget* criterion refers to the total cost of ownership which include initial investment and running costs. *Labor savings* criterion, on the other hand, refers to the effects of the project on labor costs. Digital transformation projects are expected to decrease labor efforts. In a similar manner, *Material savings* criterion refers to the effects of the projects on materials. Digital transformation projects enable better use of materials so a decrease in material costs is expected. Besides the economic effects, digital transformation projects may change the competitiveness of companies. *Effects on competitiveness* criterion refers to influence of the project on the competitiveness of the company. *Improved decision making*, is the last criterion which is taken into account.

Digitization of process enables collection of extensive data which are later used for better decision making processes. Because of the privacy concerns, details about the alternatives are not given in the paper. But the topics of the projects are as follows: DTP1: Manufacturing process traceability, DTP2: Robotics for packaging, DTP3: Additive manufacturing for experimental prototypes, DTP4: Robotics for test and inspection, DTP5: Automated robots for Warehouse management

The decision model is constructed together with the key managers of the company, taking into account literature reviews as well. The weights of the criteria are determined as: 0.25, 0.15, 0.15, 0.25, and 0.20, respectively. The managers are asked to evaluate the alternative with respect to each criterion and assign aggregated decisions. Table 2 represents the linguistic evaluations of the decision makers.

Table 2. Evaluations of the decision makers

Criterion	DTP1	DTP2	DTP3	DTP4	DTP5
C1	F	MG	VP	MP	G
C2	P	MG	P	MP	G
C3	VP	P	F	MG	MP
C4	G	MG	MG	G	F
C5	VG	MG	P	P	MG

The linguistic evaluations given in Table 1 are later transformed into Interval Valued Type-2 Intuitionistic fuzzy sets (Table 3).

Table 3. Interval Valued Type-2 Intuitionistic Fuzzy Evaluations

Criterion	DTP1	DTP2	DTP3
C1	([0.45, 0.55], [0.45, 0.55])	([0.55, 0.65], [0.35, 0.45])	([0.10, 0.20], [0.80, 0.90])
C2	([0.20, 0.35], [0.65, 0.80])	([0.55, 0.65], [0.35, 0.45])	([0.20, 0.35], [0.65, 0.80])
C3	([0.10, 0.20], [0.80, 0.90])	([0.20, 0.35], [0.65, 0.80])	([0.45, 0.55], [0.45, 0.55])
C4	([0.65, 0.80], [0.20, 0.35])	([0.55, 0.65], [0.35, 0.45])	([0.55, 0.65], [0.35, 0.45])
C5	([0.80, 0.90], [0.10, 0.20])	([0.55, 0.65], [0.35, 0.45])	([0.20, 0.35], [0.65, 0.80])

Criterion	DTP4	DTP5
C1	([0.35, 0.45], [0.55, 0.65])	([0.65, 0.80], [0.20, 0.35])
C2	([0.35, 0.45], [0.55, 0.65])	([0.65, 0.80], [0.20, 0.35])
C3	([0.55, 0.65], [0.35, 0.45])	([0.35, 0.45], [0.55, 0.65])
C4	([0.65, 0.80], [0.20, 0.35])	([0.45, 0.55], [0.45, 0.55])
C5	([0.20, 0.35], [0.65, 0.80])	([0.55, 0.65], [0.35, 0.45])

After applying the steps of the methodology, the score values of the alternatives are calculated and given in Table 4.

Table 4. Score values

Criterion	DTP1	DTP2	DTP3	DTP4	DTP5
C1	0.10	0.30	–0.60	–0.10	0.60
C2	–0.30	0.30	–0.30	–0.10	0.60
C3	–0.60	–0.30	0.10	0.30	–0.10
C4	0.60	0.30	0.30	0.60	0.10
C5	0.80	0.30	–0.30	–0.30	0.30

By using score functions, the negative ideal and positive ideals are determined. Later distances of each alternative to ideal solutions are calculated. Finally, the Closeness coefficient is calculated. The resulting values and alternative rankings are given in Table 5.

Table 5. Distances and Rankings

	DTP1	**DTP2**	**DTP3**	**DTP4**	**DTP5**
Distance to Positive Ideal	0.33	0.34	0.32	0.39	0.47
Distance to Positive Ideal	0.18	0.19	0.25	0.27	0.28
Closeness Coefficient	0.33	0.34	0.32	0.39	0.47
Ranking	4	3	5	2	1

The results reveal that DTP5 (Automated robots for Warehouse management) is the best alternative and it is followed by DTP4 (Robotics for test and inspection) and DTP2 (Robotics for packaging).

5 Conclusion

DT is shifting the flow of the business operations and management. By using DT existing industries are being redesigned and new business models are created. Prioritizing the projects and initiating the right projects generate a significant business performance. In this study, a decision model for DT project prioritization is proposed and the decision model is solved by using Interval Valued Type-2 Intuitionistic fuzzy TOPSIS method.

The generalizability of the results is very low but the decision model and method can be used in different conditions with different alternatives. For future studies, DT project selection problem can be solved by using other extensions of fuzzy sets such as circular fuzzy sets, picture fuzzy sets, and *q*-rung orthopair fuzzy sets. The results provided by these methods can be compared with the results of this study.

References

[1] Atanassov, K. T. (1989). More on intuitionistic fuzzy set, *Fuzzy Sets and Systems*, 33(1), 37–45.

[2] Berghaus, S., & Back, A. (2017). Disentangling the fuzzy front end of digital transformation: Activities and approaches. International Conference on Information Systems (ICIS) 2017, Seoul, Korea, 1–17.

[3] Chen, C.-L., Pn, Y.-C., Chen, W.-H., Chao, C.-F., & Pandia, H. (2021). Role of government to enhance digital transformation in small service business. *Sustainability*, 13, Article No. 1028.

[4] Dehning, B., Richardson, V. J., & Zmud, R. W. (2003). The value relevance of announcements of transformational information technology investments. *MIS Quarterly*, 27(4), 637–656.

[5] EIT Report (2021). EIT RawMaterials publishes Position Paper on digitalisation in the raw materials sector. Retrieved from `https://eitrawmaterials.eu/eit-rawmaterials-publishes-position-paper-on-digitalisation-in-the-raw-materials-sector/`. Accessed August 18, 2022.

[6] Englmair, F., & Flack, O. (2020). Job market boom or oppressive change? The effects of the digital transformation on the workplace and the labor market. *CESifo Forum*, 21(3), 3–4.

[7] Hess, T., Matt, C., Benlian, A., & Wiesbock, F. (2016). Options for formulating a digital transformation strategy. *MIS Quarterly Executive*, 15(2), 103–119.

[8] Isikli, E., Ugurlu, S., Cevikcan, E., & Ustundag, A. (2017). Project portfolio selection for the digital transformation era. In: *Industry 4.0: Managing the Digital Transformation* (pp. 105–121). Springer Cham.

[9] Jeansson, J., & Bredmar, K. (2019). Digital transformation of smes: capturing complexity. In: A. Pucihar, M. Kljajić Borštnar, R. Bons, J. Seitz, H. Cripps, & D. Vidmar (Eds.), *32nd Bled eConference, Humanizing Technology for a Sustainable Society* (pp. 523–541). University of Maribor Press.

[10] Kahraman C., Cevik Onar S., Oztaysi B. (2015) Engineering economic analyses using intuitionistic and hesitant fuzzy sets, Jou*rnal of Intelligent & Fuzzy Systems*, 29(3), 1151–1168.

[11] Kane, G., Palmer, D., & Phillips, A. N. (2015). Is your business ready for a digital future. *MIT Sloan Management Review*, 56, 37–44.

[12] Kaya, İ., Oztaysi, B., & Kahraman, C. (2012). A two-phased fuzzy multicriteria selection among public transportation investments for policy-making and risk governance. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 20(1), 31–48.

[13] Lucas, H. C., Agarwal, R., Clemons, E. K., El Sawy, O. A., & Weber, B. (2013). Impactful research on transformational information technology: An opportunity to inform new audiences. *MIS Quarterly*, 37(2), 371–382.

[14] Matt, C., Hess, T., & Benlian, A. (2015). Digital transformation strategies. *Business & Information Systems Engineering*, 57(5), 339–343.

[15] Otay, I., & Jaller, M. (2020). Multi-criteria and multi-expert wind power farm location selection using a Pythagorean fuzzy Analytic Hierarchy Process. In: Kahraman, C., Cebi, S., Cevik Onar, S., Oztaysi, B., Tolga, A. & Sari, I. (Eds.), *INFUS 2019 Intelligent and Fuzzy Techniques in Big Data Analytics and Decision Making*, Advances in Intelligent Systems and Computing Vol. 1029 (pp. 905–914). Springer, Cham.

[16] Oztaysi, B., Behret, H., Kabak, O, Ucal Sarı, I., & Kahraman, C. (2013). Fuzzy inference systems for disaster response. In: Vitoriano, B., Montero, J., Ruan, D. (eds) Decision Aid

Models for Disaster Management and Emergencies. Atlantis Computational Intelligence Systems, Vol 7 (pp. 75–94). Atlantis Press, Paris.

[17] Oztaysi, B., Cevik Onar, S., & Kahraman, C. (2016). Fuzzy multicriteria prioritization of Urban transformation projects for Istanbul. *Journal of Intelligent & Fuzzy Systems*, 30(4), 2459–2474.

[18] Oztaysi, B., Cevik Onar, S., & Kahraman, C. (2018). Prioritization of business analytics projects using interval type-2 fuzzy AHP. In: Kacprzyk, J., Szmidt, E., Zadrożny, S., Atanassov, K., & Krawczak, M. (Eds.), *EUSFLAT 2017 Advances in Fuzzy Logic and Technology*, Advances in Intelligent Systems and Computing, Vol. 643 (pp. 106–117), Springer, Cham.

[19] Song, S., Yang, F., & Xia, Q. (2019). Multi-criteria project portfolio selection and scheduling problem based on acceptability analysis. *Computers & Industrial Engineering*, 135, 793–799.

[20] Wade, M. R. (2015). Digital business transformation: A conceptual framework. Global Center for Digital Business Transformation. Retrieved from `https://www.imd.org/globalassets/dbt/docs/framework`. Accessed August 18, 2022.