Identifying and Prioritizing Digital Transformation Elements Using Fuzzy Analytic Hierarchy Process

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***Abstract*—Digital transformation addresses multiple aspects of the organization. These aspects are the elements to be addressed for the digital transformation in any organization and are categorized as dimensions and sub-dimensions. In this work, these elements are collected from a wide range of related literature (56 publications). The most relevant elements were then identified through expert survey; involving 12 experts. The weights for these elements were identified using multi-criteria decision-making (MCDM) techniques. The Analytical Hierarchy Process (AHP) is one of the most often used MCDM techniques to incorporate individual and subjective preferences when conducting analysis and convert complex issues into a clear hierarchical structure. This work applies fuzzy AHP to take into consideration the treatment of uncertainty issues (in AHP), using the geometric mean method, and through an iterative process, calculate the weights of various dimensions and sub-dimensions, and prioritize them within the proposed roadmap for digital transformation implementation. Sensitivity analysis and comparison with AHP were used to validate our findings and the robustness of our approach. The proposed approach identified 9 main dimensions and 42 sub-dimensions which align with the majority of the literature. However, the advantage of this approach is the prioritization of these nine dimensions and their sub-dimensions as per the weights assigned to each one of them, allowing the project manager to allocate the available resources to the dimensions with the highest priority. The results show that the strategy and business process dimensions are the most crucial ones in the implementation of digital transformation.**

Keywords—Digital transformation; MCDM; AHP; fuzzy AHP introduction

I. Introduction

Digital Transformation (DT) has become an essential part of human life, and it is necessary for almost every private and public sector seeking growth, expansion, quality, and sustainability [1]. It can also change our life, work, increase productivity, save money, and reduce effort. In order to benefit from these advantages, several countries have started launching digital transformation projects such as [2-3]. Moreover, private sectors have also embraced DT, with organizations implementing their own DT programs [4]. However, it is important to note that every organization operates in a unique context and may be at a different stage of implementing DT. Therefore, it is essential for both public and private sectors to have an approach that allows them to assess their current position in DT implementation, identify strengths and weaknesses, and develop strategies to overcome any challenges [5]. By understanding their current state and addressing weaknesses, organizations can enhance their DT efforts and achieve greater success in embracing the advantages of DT. This approach is called digital maturity model, readiness tests, or frameworks. It has two objectives: 1) the first objective is used to define the current position in the context of DT, and 2) the second objective is to propose a roadmap for implementation of DT. Organizations need a roadmap to clearly understand the DT concepts involved and effectively implement DT. The formulation of the roadmap poses a major challenge given the large variety of frequently occurring dimensions and sub-dimensions (criteria) that necessitate the use of a decision support technique called Multiple Criteria Decision Making (MCDM) [6]. To handle the large variation between the decision makers' opinions, Saaty [7] proposed AHP in order to streamline complex multi-decision-making processes and make them more systematic. AHP resolves complicated scenarios, including multiple criteria in the decision-making process by converting to a hierarchical structure [7-8]. Following the creation of the hierarchical structure, any two criteria are compared using pairwise comparison. There are three primary steps that make up the AHP: 1) define the goal and hierarchical structure of the study, 2) construct pairwise comparisons between criteria at each level of structure, and 3) calculate weight and ranking. AHP is the most widely used among MCDM techniques in domains, such as software [7] and industry [8]. Downsides with uncertainty associated with the decision-makers judgment can be solved by combining AHP and fuzzy set theory [10], [11-14].

To the best of our knowledge, the majority of studies look at how to evaluate digital transformation by defining the dimensions and sub-dimensions of digital transformation in the private or public sector and setting priorities for their implementation, but no study has taken more attention to a comprehensive approach that takes into account both .The study aims to address the gap in research by taking a comprehensive approach to evaluating DT in both the private and public sectors. It encompasses two key aspects: Firstly, the comprehensive synthesis of diverse elements, including dimensions and sub-dimensions, to DT within both the private and public domains. Secondly, the introduction of a hybrid approach—the combining of the Fuzzy Analytic Hierarchy Process (FAHP) with the Analytic Hierarchy Process (AHP)—designed to effectively prioritize the implementation of digital transformation components. The output of this prioritization will serve as the basis for a future roadmap proposal. Conducting such a study could help identify commonalities and differences between sectors, enabling a more effective allocation of resources and prioritization of implementation strategies. The rest of the paper is organized as follows: Section II presents a literature review of the relevant literature on the topic. Section III discusses the research methodology employed in the study is discussed in detail; Section IV discusses the results of our approach. Section V validates the results of the hybrid approach by using sensitivity analysis and comparison with AHP, and in the finally section, the conclusion and future work are presented.

II. Literature Reviews

Selecting the appropriate maturity components, such as dimensions and sub-dimensions, and computing the weights requires an analytical and scientific approach, as follows in our work:

A. Approaches to Weight Dimensions and Sub-Dimensions in DT

According to our literature review, there are two most common methods for defining weights for dimensions and sub-dimensions:

- The first method involves calculating the arithmetic mean.

In this procedure, specialists assign a separate value to each dimension and sub-dimension [15-18]. These values are then used to calculate mean values, which are considered as weights for each dimension and sub-dimension.

- The second method relies on MCDM

The second approach employs Multi-Criteria Decision Making (MCDM) techniques. In this method, experts assign comparative values to each dimension relative to the other dimensions. Likewise, they assign values to each sub-dimension relative to other sub-dimensions within the same dimension. Several studies have proposed various methodologies for prioritizing DT in different domains. For instance, [8] introduced an AHP-based approach for Industry 4.0,[13] employed Fermatean AHP for Supply Chain prioritization, [19] presented a method for technology selection in DT, [20] combined SF-AHP and SF-TODIM approaches in the defense industry, [21] devised a DEMATEL-based method for assessing DT in the health sector, [22] utilized ANP for evaluating DT in manufacturing, [23] introduced a fuzzy TOPSIS-based approach for supplier evaluation in DT within production systems and [24] employed Shannon entropy to calculate Business digital maturity in Europe Analysis of previous research reveals that many studies focused on the private sector, and there is not the same level of interest in the public sector.

B. Determining the DT Dimensions and Sub-dimensions

The literature review encompassed a thorough examination of assessment frameworks related to DT. This involved extracting DT maturity dimensions and their corresponding sub-dimensions from various studies [25-73]. The selection of these studies was based on their relevance to DT assessment requirements. The outcome of the literature review revealed a total of nine main dimensions and 168 corresponding sub-dimensions related to DT maturity. However, in order to streamline the assessment framework, only the most frequently occurring sub-dimensions, with a frequency of two or more, were chosen. As a result, the sub-dimensions were reduced to a more manageable number of 70.

The results of the literature review to define dimensions and sub-dimensions can be summarized in Table I.

III. Research Methodology

Based on a thorough study of the literature [25-73], including comparisons of digital maturity assessment in the field of DT and expert reviews. This research employs an iterative and tested approach to construct an assessment framework in DT [14–15] and [8]. Overall, research methodology has a two-phase process, namely:

- Defining dimensions and sub-dimensions in DT
- Derivation of weights via a hybrid approach (FAHP with AHP)

The output of phase one is used as an input to phase two. Each phase will be discussed as follows:

A. Defining Dimensions and Sub-dimensions in DT

In Section II (B), drawing on the literature review, a first draft of the dimensions and sub-dimensions is defined. As described earlier, we need a way to identify the most relevant sub-dimensions for evaluating digital transformation. To achieve this, a review of the first draft with DT specialists (12) was conducted to capture the final relevant dimensions that were identified for further weight derivation. The summary of the methods used in this phase is shown in Fig. 1.

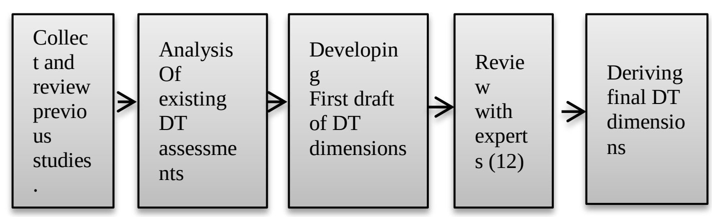

Fig. 1. Flow diagram of the first phase.

B. Deriving Weights Using Hybrid Approach

As mentioned before, the aim of this research is to use the MCDM approach to prioritize the implementation of DT dimensions and sub-dimensions. This is done by proposing a hybrid approach that combines fuzzy group theory with the AHP method. Fig. 2 shows the proposed methodology. An overview of our approach will be given as follows:

- Step 1: Defining Problem and Planning: Define the objective of the study, define DT elements, and decompose the problem into a hierarchical structure.
- Step 2: Construct pair-wise comparisons at each level of the hierarchy structure by using fuzzy numbers.

The fuzzy scale used in the research [13] was employed to facilitate pairwise comparisons between DT elements, such as dimensions or sub-dimensions).

A is a n*n pairwise matrix in which the relative importance of pairwise comparisons is determined on a scale of 1 to 9.

TABLE I. DT DIMENSIONS AND SUB-DIMENSIONS OF DT FROM LITERATURE REVIEWS

Dimensions Name	Sub-dimensions Name
Customer [25-29] [-51]	customer experience [25-26], customer insight and analytics [27-28], competence with modern ICT [47-48], customer training [48-49], customer centricity [26][47][50] and customer integration[49-51]
Technology[25] [31-33] [36-38] [41-58] [59-61]	exploitation new technology AI, cloud computing, big data[25][36-38][56-61], IT architecture[31-33] [41-58], integration systems layer[25], Use technology for data collection [36-38] [41-58] [59-61], technology driven[31-33][42][59], digital capabilities[25][31-33], IT Infrastructure[31-33] [41-58], IT standard[33][36-38], effective technology planning[31-33][42][59], IT governance[25][31-33],, define digital transformation requirements[61], and IT security[41-58].
Strategy [25-36][39] [45-46] [49] , [65-66]	coordination of digital transformation activities[25-30], strategic governance[26-30], technology investments[47][49][50], risk assessment for digital transformation[39-44], ecosystem management[60-64], stakeholder management[64-66] , strategic alignment [27][60][66],digital transformation vision[25-28][461-63], transformation in digital leadership[25-36], define role, Standards[62-64],, top management commitment to realize digital transformation [47][49][50], and cost benefit analysis[45-46].
Organization [26-28] [31-32] [35-38] [45] [49] [52][57] [67-68],	organizational structure [26-28][31-32], organization collaboration[52][57], transformation in digital leadership[35[38][45], organization 47governance[52][67-68], change management[31][32][57][68], cross functional collaboration [35-38][67], training[68], sufficient financial resources[32], and digital portfolio management[45].
Processes process[30][35-36] [39][42] [65] [69-70],	business process integration [30][35-36][39], business process performance management[42][69-70], business process standard[39][42] [65], business process security[30][42] [65], transformation in digital leadership[42][69-70], quality of business processes[39][69-70], Process control, intelligent process management[70]; reduce the costs of business process [42] and real-time insights & analytics [69-70].
Culture[26-27][31][42][45-46] [53-54]	Innovative culture [26-27], openness to change [26][42][45], communication[45-46][53], everyone is allowed to make decisions45-46][53-54], open environment[31] and digital education[53].
Data[26-27][33] [35] [48][50][65] [67]	data analysis [26-27][33] [35] [48][50][65] [67], data management[33] [35] [48][50], data security and privacy[26-27][33] [35], data governance[[33][48][67], data quality[67], data visualization[33][65] and data archiving[48].
Employee[26-27][42][45] [52][72]	Openness to new technology [26-27] [42] [45], willingness to change [52] [72] and employee training. [26-27] [42][45] [52] [72].
Citizen [72-73].	Citizen training [72-73], citizen skills [72-73] and citizen centricity [72-73].

$$\tilde{A}^k = \begin{bmatrix} \tilde{d}_{11}^k & \tilde{d}_{12}^k & \dots & \tilde{d}_{1n}^k \\ \tilde{d}_{21}^k & \dots & \dots & \tilde{d}_{2n}^k \\ \dots & \dots & \dots & \cdots \\ \tilde{d}_{n1}^k & \tilde{d}_{n2}^k & \dots & \tilde{d}_{nn}^k \end{bmatrix} \tag{1}$$

Where $\tilde{d}_{ij}^k$ indicates the Jth decision maker's preference of ith criterion over the jth criterion, via fuzzy a triangular numbers. It is fuzzy number (l, m, u) [13], for reciprocal:

$$d_i\tilde{k}^{-1} = (l, u.m)^{-1} = (\frac{1}{u}, \frac{1}{m}, \frac{1}{l}) \tag{2}$$

Twelve decision makers "experts" consist of DT consultants and academics, which are considered experts in their respective fields abbreviated as E1, E2, E12. By collecting the opinions of these decision-makers and constructing the pairwise comparison matrix using Eq. (1), it becomes possible to determine the relative of each dimension and sub-dimension Pairwise comparisons of the fuzzy judgment matrix "i" are frequently inconsistent because they are prone to bias and inaccuracy in preference for expert responses. Therefore, AHP is used to avoid inconsistencies in responses. The consistency index for pairwise comparisons was calculated by using Eq. (3).

$$\lambda\max = \frac{1}{n}\sum_{j=1}^{n}\frac{Awi}{wi} \tag{3}$$

$$CI = \frac{\lambda\max - n}{n-1} \tag{4}$$

Where n is the number of dimensions or sub- dimensions

Eq. (5) is used to calculate the consistency ratio, where CI is compared with a random index.

$$CR = \frac{CI}{RI} \tag{5}$$

- Step 3: Check consistencies (for the most likely value)

This random index (RI) value [12] is correlated to the number of dimensions or sub-dimensions compared and used to calculate the consistency ratio, as shown in Eq. (5). The level of consistency is acceptable if the CR is less than 0.1. If not, there will likely be a lot of inconsistency, so the opinion of the decision-maker will be deleted. In this study, the CI is calculated for the middle value (most likely value “m”) [11], even though the pairwise comparison indices (relative importance) of the judgment matrix are TFNs for each decision-maker separately. In this work, we calculate the consistency ratio for each expert separately. If the consistency index exceeds 0.1, the opinion of this expert will be deleted.

- Step 4: Aggregate expert opinions

If there are many decision makers accepted$\tilde{d}_{ij}$, the average” $\tilde{d}_{ij}$ “is calculated using Eq. (6) [13].

$$\tilde{d}_{ij} = \frac{\sum_{k=1}^{k}\tilde{d}_{ij}^k}{k} \tag{6}$$

According to averaged preferences, pair wise contribution matrices are updated as shown in Eq. (7).

$$\tilde{A} = \begin{bmatrix} \tilde{d}_{11}^k & \cdots & \tilde{d}_{1n}^k \\ \vdots & \ddots & \vdots \\ \tilde{d}_{n1}^k & \cdots & \tilde{d}_{nn}^k \end{bmatrix} \tag{7}$$

- Step 5: Calculate CR to Aggregate Expert Opinions

Pair-wise comparisons were constructed for the opinions of decision-makers based on Eq. (6), and then a new CR was calculated for this matrix using Eq. (5).

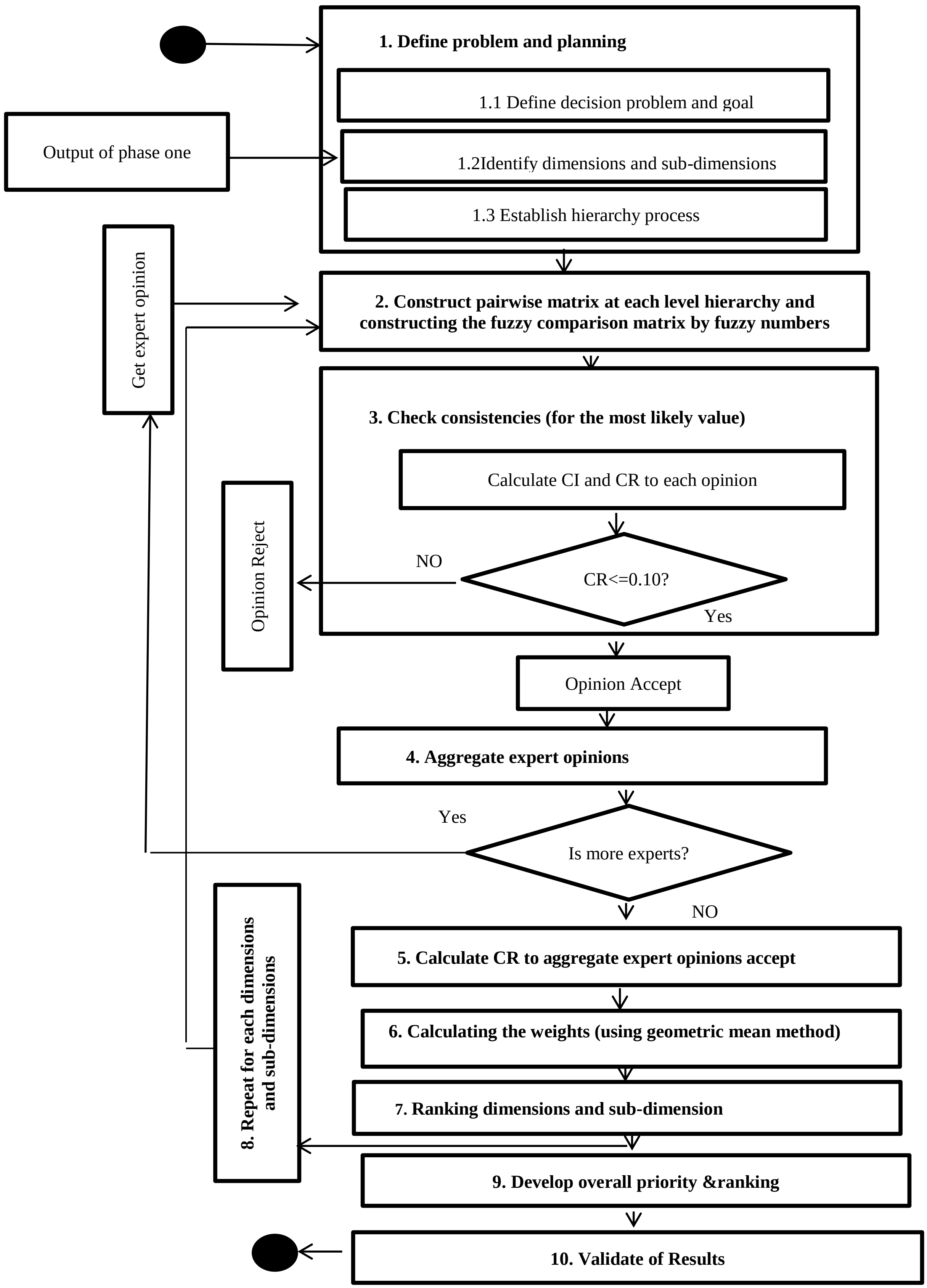

Fig. 2. Flowchart of the proposed methodology of the second phase.

- Step 6: Calculating the weights Using Fuzzy Geometric Mean Method.

As mentioned before, the major problem of AHP has been enhanced by utilizing fuzzy logic since it does not include vagueness for subjective judgments. There are several approaches to F-AHP, such as the geometric mean [11], [14], [64-65], and the extent analysis method [66]. In this work, the fuzzy geometric mean method was used to calculate the weights.

The sixth step contains several sub-steps that can be summarized as follows:

Step 6.1**:** According to [64] and [13], the fuzzy geometric mean value of each sub-dimension or dimension is calculated using Eq. (8). Here$\tilde{r}_i$, it still represents triangular values.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n},\ i = 1,2,\dots,n \tag{8}$$

Where n is the number of dimensions or sub-dimensions.

Step 6.2: Find the vector summation of each $\widetilde{r_1}$.

Step 6.3**:** Find the (-1) power of the summation vector. Replace the fuzzy triangular number, to make it in an increasing order [13].

Step 6.4: The fuzzy weight of dimensions or sub-dimensions was calculated as shown in Eq. (9).

$$\widetilde{w}_i = \widetilde{r_1} \otimes (\widetilde{r_1} \oplus \widetilde{r_2} \oplus \dots \oplus \widetilde{r_n})^{-1} = (\,lw_i, Lw_i, mw_i, uw_i) \tag{9}$$

Step 6.4: The weights that have been calculated by using Eq. (8) are still fuzzy triangular numbers, so we need to de-fuzzified them by the Centre of Area (COA) as shown in Eq. (10) [13].

$$Wi = \frac{l+m+u}{3} \tag{10}$$

Step 6.5: The weights that come from Eq. (9) were normalized as shown in Eq. (11).

$$Ni = \frac{Mi}{\sum_{i=1}^{n} Mi} \tag{11}$$

- Step 7: Ranking of dimensions and sub-dimensions.

Based on the outputs of step seven, the dimensions and sub-dimensions can be ranked according to weights.

- Step 8: Repeat steps 3, 4, and 5 for all levels of the hierarchy.
- Step 9: Develop overall priority & ranking.

According to [9], the total weight of sub-dimensions can be calculated according to Eq. (12), where “I” is the weight of dimensions and “j” is the weight of sub-dimensions in each dimension.

$$tij = gi\ x\ wij \tag{12}$$

- Step 10: Validate of Results

The Sensitivity analysis and comparison with AHP were used to validate of our approach.

IV. Results and Discussion

In this section, we used the proposed method presented in Section III, as illustrated in in Fig. 1 and 2 to define and prioritize the dimensions and sub-dimensions of digital transformation. It will be discussed as follows:

A. DT Dimensions and Sub- dimensions

The results of the review with experts (applying Method 1 in Fig. 1) to define relevant dimensions and sub-dimensions are summarized in Table II. After conducting the review with experts to determine the most important sub-dimensions in evaluating digital transformation, the sub-dimensions were reduced to 42.

TABLE II. DT Dimensions and Sub-Dimensions After Review with Experts

Dimensions	***Sub-dimensions***
Customer	Customer training, Customer centricity, Customer integration
Technology	IT Architecture, Technology driven, Technologysecurity ,IT governance, Exploitation new technology,Use technology for data collection ,Digital Capabilities, IT Infrastructure, IT standard, Effective technology planning
Strategy	Coordination of digital transformation activities, Strategic governance, Technology investments, Risk assessment for digital transformation , Ecosystem Management, Stakeholder Management, Strategic alignment (Business-IT alignment) ,Digital transformation vision, Transformation in Digital Leadership
Organization	Transformation in digital leadership, Organization governance, Digital change management, Cross functional collaboration
Processes process	Business process Integration, Business process performance management , Business process standard, Business process security , Transformation in digital leadership
Culture]	Innovative culture, Openness to change,Communication, Everyone is allowed to make decisions
Data	Data analysis, Data management ,Data security and privacy,Data governance
Employees	Openness to new technology, Willingness to change, Employee training
Citizen	Citizen training, Citizen skills, Citizen centricity

B. Weights of DT Dimensions and sub-dimensions

In this section, the proposed method presented in Section III in Fig. 2 is used to prioritize the implementation of the dimensions and sub-dimensions of digital transformation by calculating weights. Fig. 3 illustrates this hierarchical structure involving the objective of the study, dimensions, and sub-dimensions.

In Fig. 3, the first level relates to the objective goal of the study. The second level corresponds to dimensions, and the last level corresponds to sub-dimensions of each dimension. In this paper, a pairwise comparison matrix will be created between elements (dimensions) in level 2. Similarly, a pairwise comparison matrix will be created between elements (sub-dimensions) in level 3 that have the same parent in level 2. Due to space constraints, the results of the steps involved in the proposed method are presented for the main dimensions on level 2, as shown in subsection A.

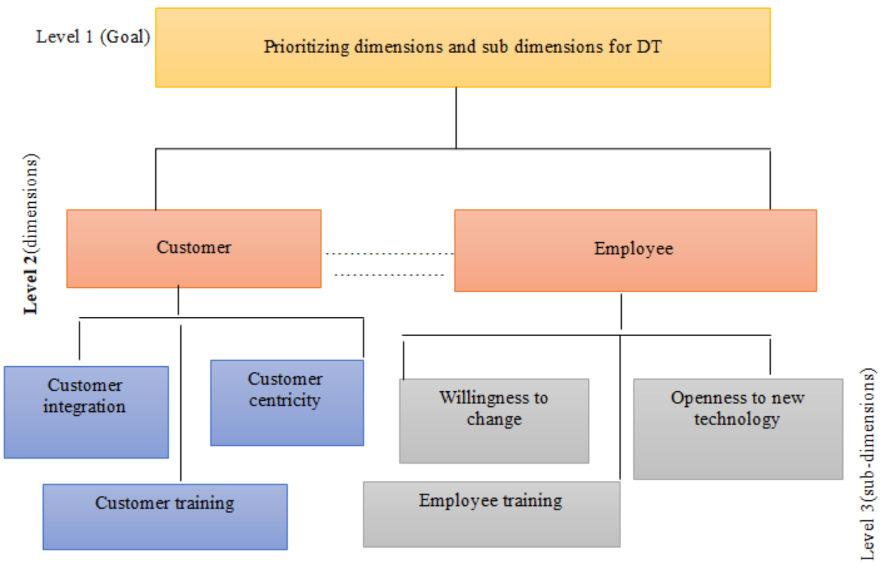

Fig. 3. Example DT Hierarchy structure of the problem.

C. *Weights of DT Dimensions*

The results of the steps involved in the proposed method are presented for the pairwise comparison matrix between the main dimensions on level 2, as well as the output of each step. For each expert out of 12, a pairwise matrix was created, but due to the difficulty of displaying all of them, it was sufficient to present a matrix for one expert, as shown in Table III. Then consistency is checked for each expert (E) separately, as shown in Table IV. Only four expert opinions were accepted, while eight expert opinions were omitted, as shown in Table IV. The opinions of the experts accepted in the previous step were collected, as shown in Table V. The consistency ratio of the opinions of the accepted experts is calculated based on Table V. Consistency ratio = 0.064003. The outputs of applying Eq. (8), (9), and (10) and Step 7 are summarized in Table VII. From Table VI, it can be noticed that the strategy dimension has the highest weight (priority) “0.341” followed by the business process with a weight “0.215”. Thus, the strategy dimension will rank first, followed by the business process. It can also be seen that the citizen dimension has the least weight (0.030).

D. *Weights of Sub-dimensions*

As previously mentioned, due to space limitations, the results of the steps involved in the proposed method will not be presented for the main dimensions at Level 3, but the final results for the respective weights for each sub-dimension will be shown in Table VII.

E. *Total Weights of each Sub-dimensions*

As we mentioned before, the total overall weight of each sub-dimension (t) can be calculated according to Eq. (12). The results of applying step eight can be summarized in Table VIII. For example, in” digital transformation vision”, gi=0.341, wij=0.355, so tij=0.121. After calculating tij for all, it can be ranked. Based on the outputs of Table VII, it is possible to arrange the implementation of the sub-dimensions in relation to digital transformation. "Digital transformation vision" was first ranked, "business process standard" was placed second, and "integration of citizens" came in last ranked. So it can be said that “digital transformation vision" is the leading factor for DT, followed by "business process standard". One other salient sub-dimension is willingness of employees to change" followed by "business-IT alignment". The consistency analysis of this research is summarized in Table VIII. Fig. 4 shows an incremental comparison of the total weights of all sub-dimensions (t) in detail.

V. Results Validations

In this section, our work will be evaluated by identifying the advantages of this work compared to the research that is most similar to it [8] and comparing the results of our work with the results of AHP, in addition to using the Sensitive Analysis.

A. *Comparison with Prior Study*

In order to contextualize our research, it's imperative to draw comparisons with a prior study [8]. This prior research shares the commendable attribute of employing a coherent methodology to delineate and assign weights to DT elements. Nonetheless, the preceding study harbors three notable limitations: it confines its focus solely on the private sector for the definition of DT elements, employs the AHP to prioritize these elements despite inherent uncertainties, and regrettably omits result validation. In response to these challenges, this research endeavors to address them comprehensively. The first limitation was overcome by the comprehensive identifying of elements relevant to DT evaluation in general (both segments). The second challenge is strategically navigated by adopting a combined approach, unifying AHP with FAHP to bolster consistency and mitigate the uncertainties often associated with expert judgments. Furthermore, a rigorous sensitivity analysis was performed to validate the results, critically addressing the last limitation. In doing so, our research not only endeavors to provide a comprehensive solution but also contributes to the broader scholarly discourse on digital transformation assessment methodologies.

B. Comparison Results (Ranking)

A comparative analysis is performed to validate the effectiveness of our proposed approach by comparing the results of our approach with those of AHP as follows:

- Comparing the ranking between the main dimensions

Based on the results obtained, it can be observed that the ranking of the main dimensions using the Analytic Hierarchy Process (AHP) is the same as the ranking using fuzzy AHP, with the exception of the business process and employee dimensions as shown in Fig. 5. In AHP, the business process dimension is ranked third, whereas in fuzzy AHP, it is ranked second. Similarly, the employee dimension is ranked second in AHP and third in fuzzy AHP. Comparative analysis of the results indicates that our approach is 80% compatible with AHP in terms of dimensional order. This suggests that there is a significant level of agreement between the two methods, except for the specific dimensions mentioned above.

- Comparing the ranking between the sub-dimensions in each dimension

Due to space limitations, only the sub-dimensions rank of the data dimension was compared. Based on the comparative results shown in Fig. 6, it can be concluded that our approach is 100% compatible with AHP in terms of the ordering of sub-dimensions in the data dimension. This indicates that our proposed approach accurately orders the implementation of dimensions in the decision tree (DT).

TABLE III. FUZZIFIED PAIRWISE MATRIX BETWEEN DIMENSIONS FOR FIRST EXPERT

	Strategy	***Business process***	***Employee***	***Data***	***Technology***	***Organization***	***Stakeholder***	***Culture***
Strategy	(1,1,1)	(1,1,1)	(4,5,6)	(6,7,8)	(1,1,1)	(4,5,6)	(2,3,4)	(2,3,4)
Business process	(1,1,1)	(1,1,1)	(2,3,4)	(6,7,8)	(4,5,6)	(6,7,8)	(6,7,8)	(6,7,8)
Employee	(01.6,.2,25)	(0.25,0.33,0.5)	(1,1,1)	(2,3,4)	(6,7,8)	(6,7,8)	(6,7,8)	(6,7,8)
Data	(0.12.0.14,0.16)	(0.12.14,0.16)	(0.25,0.33,0.5)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)
Technology	(1,1,1)	(0.16,2,0.25)	(0.12.0.14,0.16)	(0.25,0.33,0.5)	(1,1,1)	(1,1,1)	(4,5,6)	(4,5,6)
Organization	(01.6,0.2,0.25)	(0.12,0.14,0.16)	(0.12.0.14,0.16)	(0.25,0.33,0.5)	(1,1,1)	(1,1,1)	(4,5,6)	(4,5,6)
Stakeholder(customer or citizen)	(0.25,0.33,0.5)	(0.12,0.14,0.16)	(0.12.0.14,0.16)	(0.25,0.33,0.5)	(0.25,0.33,0.5)	(01.6,0.2,0.25)	(1,1,1)	(1,1,1)
Culture	(01.6,.2,25)	(0.12,0.14,0.16)	(0.12.0.14,0.16)	(1,1,1)	(1,1,1)	(01.6,0.2,0.25)	(0.25,0.33,0.5)	(0.25,0.33,0.5)

TABLE IV. CHECK CONSISTENCY FOR EACH EXPERT

Expert #	***CR***	***Decision (Accept or Reject)***
E1	0.07	Accept
E2	0.20	Reject
E3	0.19	Reject
E 4	0.03	Accept
E 5	0.06	Accept
E 6	0.25	Reject
E 7	0.16	Reject
E 8	0.02	Accept
E 9	0.13	Reject
E 10	0.11	Reject
E 11	0.10	Reject
E 12	0.16	Reject

TABLE V. FUZZIFIED PAIRWISE MATRIX BETWEEN DIMENSIONS FOR ACCEPT OPINIONS

	Strategy	***Business process***	***Employee***	***Data***	***Technology***	***Organization***	***stakeholder***	***Culture***
Strategy	(1,1,1)	(1,1,1)	(4,5,6)	(2.44,2.64,2.82)	(1,1,1)	(4.89,5.91,6.92)	(4.24,5.19,6)	(4.24,5.19,6)
Business process	(1,1,1)	(1,1,1)	(4.24,5.19,6)	(4.89,5.91,6.92)	(4,5,6)	(6,7,8)	(6,7,8)	(6,7,8)
Employee	(0.16,2,0.25)	(0.16,0.19,0.23)	(1,1,1)	(1.41.1.73,2)	(3.46,4.58,5.66)	(3.46,4.58,5.66)	(2.44,2.64,2.82)	(2.44,2.64,2.82)
Data	(0.35,0.37,40)	(0.14,0.16,0.20)	(0.5,0.57,0.70)	(1,1,1)	(1.41.1.73,2)	(3.46,4.58,5.65)	(3.46,4.58,5.66)	(3.46,4.58,5.66)
Technology	(1,1,1)	(0.16,2,0.25)	(0.17,0.21,0.28)	(0.5,0.57,0.70)	(1,1,1)	(2.44,2.64,2.82)	(4.89,5.91,6.98)	(4.89,5.91,6.98)
Organization	(0.14,0.16,0.20)	(0.12,0.14,0.16)	(0.17,0.21,0.28)	(0.17,0.21,0.28)	(0.35,0.37,.40)	(1,1,1)	(2,2.2,2.44)	(2,2.2,2.44)
Stakeholder**customer or citizen	(0.16,0.19,0.23)	(0.12,0.14,0.16)	(0.35,0.37,40)	(0.17,0.21,0.28)	(0.14,0.16,0.20)	(0.40,0.45,0.5)	(1,1,1)	(1,1,1)
Culture	(0.16,0.19,0.23)	(0.12,0.14,0.16)	(0.35,0.37,40)	(0.17,0.21,0.28)	(0.14,0.16,0.20)	(0.40,0.45,0.5)	(1,1,1)	(1,1,1)

TABLE VI. WEIGHT OF DIMENSIONS USING GEOMETRIC MEAN

Dimension Name	***Fuzzy wi***	***Centre of Area (COA)***	***Normalized wi***	***Rank***
Strategy	0.251,0.352,0.455	0.353	0.341	1
Business process	0.167,0.223,0.277	0.222	0.215	2
Employee	0.093,0.136,0.182	0.137	0.132	3
Data	0.070,0.097,0.216	0.128	0.123	4
Technology	0.064,0.084,0.108	0.085	0.083	5
Organization	0.032,0.043,0.057	0.044	0.042	6
Customer	0.025,0.033,0.045	0.034	0.033	7
Culture	0.024,0.033,0.045	0.033	0.030	9
Citizen	0.022,0.031,0.043	0.032	0.031	8

TABLE VII. WEIGHTING AND RANKING OF DT DIMENSIONS AND SUB-DIMENSIONS

Dimensions Name	***Weights of dimensions (g)***	***Sub-dimensions Name***	***Weights of sub-dimensions (w)***	***Total Weights (g*w)***	***Ranking Sub-dimensions***
Strategy	0.341	Digital transformation vision	0.355	0.121	1
		Coordination of digital transformation activities	0.243	0.082	4
		Business-IT alignment	0.154	0.052	7
		Technology investments	0.084	0.028	10
		Governance	0.072	0.024	11
		Ecosystem Management	0.039	0.013	20
		Stakeholder Management	0.029	0.0098	24
		Risk assessment for digital transformation	0.023	0.0078	29
Business process	0.215	Business process standard	0.55	0.1183	2
		Business process performance management	0.26	0.0559	6
		Business process Integration	0.14	0.0301	9
		Business process security	0.06	0.0129	21

Employee	0.132	Willingness to change	0.7380	0.0974	3
		Openness to new technology	0.1680	0.0222	12
		Employee training	0.0940	0.0124	22
Data	0.123	Data Analysis	0.5050	0.0621	5
		Data management	0.2750	0.0338	8
		Data security	0.1380	0.0170	17
		Data governance	0.0820	0.0101	23
Technology	0.083	technology planning	0.2320	0.0193	14
		Exploitation new technology	0.1180	0.0098	25
		Technology driven	0.1120	0.0093	26
		Technology security	0.1070	0.0089	27
		IT Infrastructure	0.0920	0.0076	30
		IT Architecture	0.0870	0.0072	31
		Use technology for data collection	0.0690	0.0057	36
		Digital Capabilities	0.0710	0.0059	35
		IT standards	0.0620	0.0051	38
		IT governance	0.0500	0.0042	39
Organization	0.0420	Cross functional collaboration	0.4410	0.0185	15
		Change management	0.3200	0.0134	19
		Organizational governance	0.1500	0.0063	33
		Transformation in digital leadership	0.0890	0.0037	41
Customer	0.033	Customer centricity	0.5160	0.0170	16
		Customer training	0.1950	0.0064	32
		Customer integration	0.1560	0.0051	37
Culture	0.031	Innovative culture	0.5300	0.01643	18
		Openness to change	0.2700	0.00837	28
		communication	0.1300	0.00403	40
		make decisions	0.0800	0.00248	42
Citizen	0.030	Citizen training	0.7340	0.02202	13
		Citizen centricity	0.1980	0.00594	34
		Citizen integration	0.0660	0.00198	43

TABLE VIII. CONSISTENCY RATIO OF AHP MATRICES

Dimensions	***Consistency Ratio (CR)***
Strategy	0.069238
Business process	0.069564
Employee	0.090259
Data	0.06956
Technology	0.025044
Organization	0.021964
Customer	0.088015
Culture	0.069564
Citizen	0.089011
Overall Consistency of Dimensions	0.064003

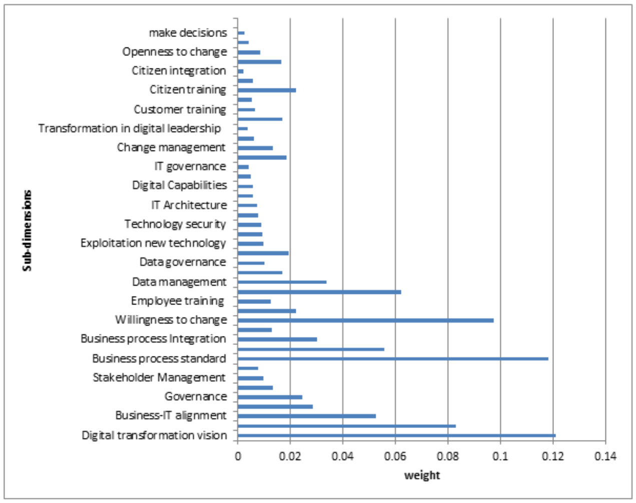

Fig. 4. Weight comparison of DT sub-dimensions

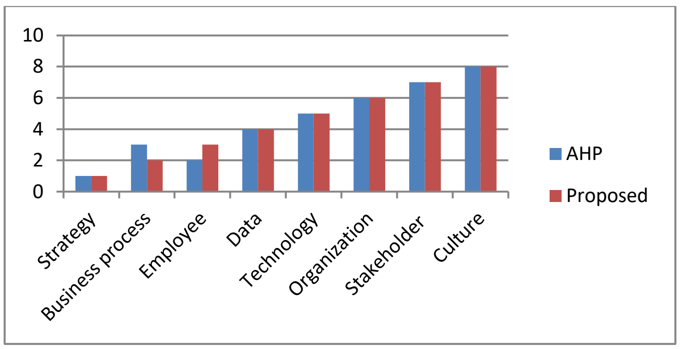

Fig. 5. Comparison results of the ranking of dimensions based on several evaluation approaches

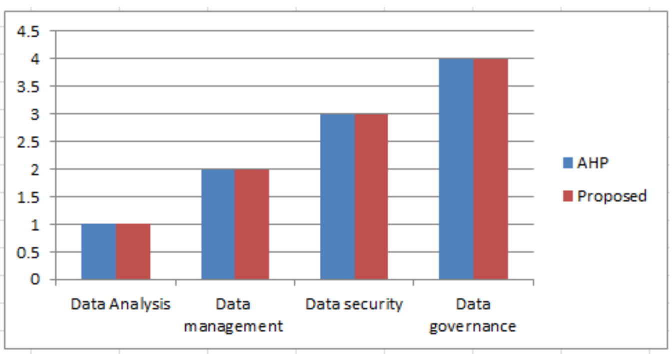

Fig. 6. Comparison results of the ranking data sub-dimensions based on several evaluation

C. Sensitivity Analysis

A sensitivity analysis is a tool to determine the effects of potential modifications in the dimension or sub-dimension weights on the prioritization of DT [13]. A sensitivity analysis was applied to the FAHP approach results based on dimensions. The X-axis represents the change in important values between 1 and 9 (that have been assigned by 12 experts) of the main dimensions or sub-dimensions, and the Y-axis represents the ranking of dimensions. We can observe the effects on the ranking of the dimensions and sub-dimensions as follows:

- Sensitive analysis in dimensions

In this analysis, the weights of a certain dimension for each expert will be changed between 1 and 9, while the weights of other dimensions are fixed. For example, when the weight of the strategy dimension with respect to the business process dimension is changed between 1 and 9, strategy has always been placed in the first rank, except for one time when business process came first, as shown in Fig. 7. This will be iterated by changing the strategic dimension values for each of the remaining dimensions. By conducting a sensitivity analysis, it was determined that the weights assigned to the primary dimension have only a slight impact on the overall results. Additionally, the order of choices does not change significantly even with variations in the weights of the primary dimensions.

- Sensitive analysis in sub-dimensions (customer as example)

Due to space constraints, only sensitivity in customer sub-dimensions was examined, as shown in Fig. 8, 9, and 10.

✓ Sensitive analysis in customer training with respect to the customer centricity

When the weight of the customer training with respect to the customer centricity is changed, the customer training has always been placed in the first rank and the customer centricity has always been placed in the second rank except one time, as shown in Fig. 8.

✓ Sensitive analysis in customer training with respect to the customer integration

When the weight of the customer training with respect to the customer integration is changed, the customer training has always been placed in the first rank and the customer integration in the second rank, as shown in Fig. 9.

✓ Sensitive analysis in customer centricity with respect to the customer integration

When the weight of customer centricity with respect to customer integration is changed, customer centricity has always been placed in the second rank, as shown in Fig. 10.

Sensitivity analysis shows that weights for the customer sub-dimensions have only a limited effect on the results, and there is no significant change in the order of the sub-dimensions.

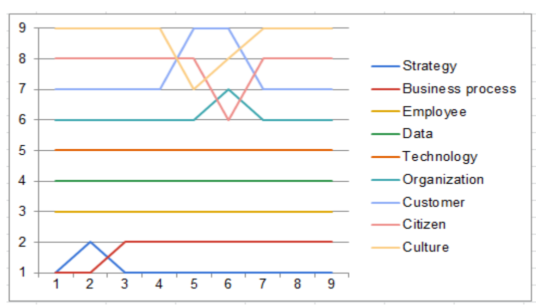

Fig. 7. Results of sensitivity analysis strategy dimension with respect to the technology dimension.

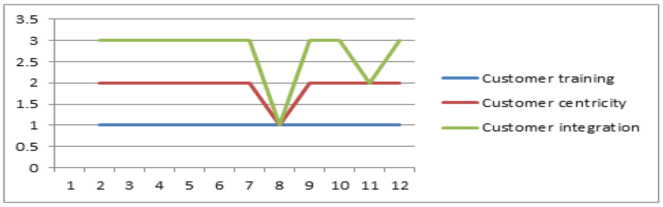

Fig. 8. Results of sensitivity analysis customer training sub-dimension with respect to the customer centricity sub-dimension.

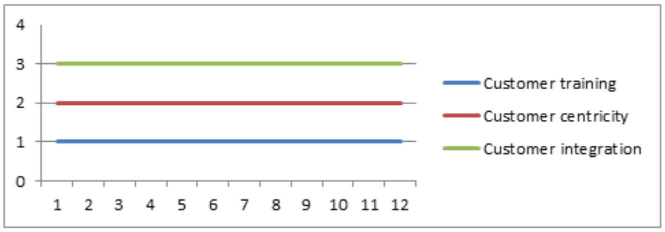

Fig. 9. Results of sensitivity analysis Customer training sub-dimension with respect to the Customer integration sub-dimension

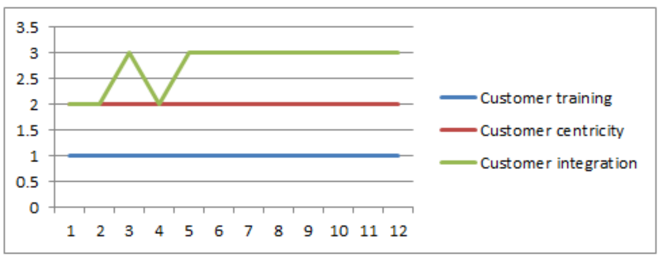

Fig. 10. Results of sensitivity analysis Customer centricity sub-dimension with respect to the Customer integration sub-dimension.

VI. CONCLUSION

The core objective of this study was to establish a systematic framework for prioritizing the implementation of dimensions and sub-dimensions within the context of digital transformation. This was achieved through two distinctive phases. The initial phase involved defining the key dimensions and sub-dimensions, drawing from prior research and expert evaluations. A comprehensive set of 42 sub-dimensions was assembled under nine primary dimensions. Subsequently, the study progressed into the second phase, where the weights of both main dimensions and sub-dimensions were meticulously computed. In this research, the integration of the fuzzy geometric mean method with AHP provided the basis for identifying priority areas of focus for organizations. The application of the fuzzy scale and geometric mean method to allocate weights to dimensions and sub-dimensions effectively handled uncertainties in the decision-making process. The inclusion of AHP further bolstered decision consistency. The findings underscored that "strategy" (0.341) and "business process" (0.215) emerged as the two pivotal dimensions within the realm of digital transformation. The sub-dimension "digital transformation vision" held the foremost position, closely trailed by "business process standard. This study carries significant implications for organizational decision-makers across both the private and public sectors. It offers a tangible pathway for identifying the priority of sub-dimensions, thereby amplifying the likelihood of successful digital transformation endeavors. Sensitivity analysis was then employed to validate the outcomes of our approach. Notably, the ranking of alternatives remained largely unchanged even when the weights of primary dimensions or sub-dimensions were modified. Furthermore, a comparative analysis was executed between our proposed approach and AHP. Through sensitivity analysis and consistency ratio calculations, the robustness and effectiveness of our approach were both established. In summation, this research introduces a methodological paradigm that guides the strategic sequencing of dimensions and sub-dimensions in digital transformation initiatives. It not only empowers decision-makers but also underscores the reliability and effectiveness of the proposed approach through rigorous analysis and validation.

- Limitation

The hybrid approach used in this paper was created exclusively for digital transformation. As well, this is a general approach and does not apply to case studies.

- Future work

Several experiments will be carried out using different MCDM techniques as well as applying our approach in many areas. The next step will be to use these findings to suggest a roadmap for the organizations when they are being evaluated.

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