International Journal of Industrial Engineering, 33(3), 547-565, 2026

CRITICAL FACTORS OF DRIVING DIGITAL TRANSFORMATION IN SMALL AND MEDIUM-SIZED RETAILERS

Tsung-Yin Ou[1, *], Stephen Donald Strombeck[2]. Hsin-Pin Fu[1], and Yi-Sin Chen[1]

[1]Department of Marketing and Distribution Management
National Kaohsiung University of Science and Technology
Kaohsiung, Taiwan R.O.C.
[*]Corresponding author's e-mail: outy@nkust.edu.tw

[2]School of Applied AI and Entrepreneurship
Handong Global University
Pohang, Korea.

The digital transformation (DT) of firms can enhance competitiveness and operational performance. However, few cases exist regarding the successful DT of small and medium-sized retailers (SMRs). So how can DT be accelerated within these enterprises? To address this question, an integrated evaluation model that combined two Multi-Criteria Decision Making (MCDM) methods was used to find the critical factors (CFs) driving DT in SMRs. Using the Technology-Organization-Environment (TOE) framework, we collected relevant extant literature to establish a three-level hierarchical structure of factors that enterprises have considered in DT. We next obtained information through a survey of top management of SMRs in Taiwan and applied the Fuzzy Analytic Hierarchy Process (FAHP) to determine the weight of each factor. Then, the concept of acceptable advantages of VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) was utilized to objectively determine the eight CFs. These CFs are: establishment of differentiation capabilities, support from senior executives, pressure from peer competition, digital infrastructure, organizational resources, industry characteristics, laws and regulations, and customer requests. This paper found that the environmental context is the driving factor of DT for SMRs rather than the technological context. Based on its other findings, this paper offers practical solutions for SMRs that are seeking to accelerate the DT process. All of these findings have implications for DT solution providers and relevant government entities who have a vested interest in growing their SMR clients/constituents.

Keywords: Digital transformation, Critical factors, Multi-Criteria Decision Making, Technology-Organization-Environment, Fuzzy Analytic Hierarchy Process, VlseKriterijumska Optimizacija I Kompromisno Resenje.

(Received on October 26, 2025; Accepted on April 23, 2026)

1. INTRODUCTION

Taiwan's retail industry has grown from 457,905 registered firms in 2007 to 496,618 firms in 2021 (MOEA, 2025). Moreover, the overall sales volume of Taiwan's retail industry was forecasted in 2022 to reach NT$4.2815 trillion (Business Next, 2023). Remarkably, 98.7% of all businesses in Taiwan are small and medium-sized enterprises (SMEs) (SMEA, 2025), and the retail sector, which is predominantly comprised of SMEs, is the largest among the service industries in Taiwan. Hence, the retail industry is a vital part of the Taiwanese economy.

With the development of information and communication technology (ICT) and the prevalence of smartphones, new business practices in the retail industry have emerged using such tools as the digitization of physical stores, artificial intelligence (AI) technology, smart stores, electronic payment, and self-service consumption, all of which are driving the growth of e-commerce and mobile commerce. As such, digitalization has become a core feature of various business activities in different organizations, fostering cost-effectiveness for businesses and numerous benefits to consumers (Sundaram *et al*., 2020). The accelerated changes in consumer shopping habits (most notably from the advent of COVID-19), enhanced accessibility to data, improved operational efficiencies, reduced operating costs, and increased competitiveness have caused the retail industry to undergo digital transformation (DT) (Reinartz *et al*., 2019; Savastano *et al*., 2022) as an efficacious means to survive and even thrive in today's market (Jackson, 2019).

Digital transformation refers to the way in which a company changes its strategies, structures, operations, and people to adapt to new technologies and customer preferences. Such changes include modifications to corporate structures, practices, values and beliefs as well as any constituent relationships with other organizations, ecosystems, suppliers, and consumers

DOI: 10.23055/ijietap.2026.33.3.11473 **ISSN 1072-4761**

(Ponsignon *et al*., 2019; AlNuaimi *et al*., 2022; Kraft *et al*., 2022). DT benefits SMEs by facilitating change and technological adaptation, and it enables improved competitiveness through agility, innovation and efficiency (Ruso *et al*., 2024). SMEs that embrace the digital transformation process will undoubtedly face serious challenges and difficulties. Therefore, SMEs need sufficient capital investments and ongoing employee training to address these challenges (Li, 2020). However, there is considerable confusion and misunderstanding in the industry about DT (Gong & Ribiere, 2021). Much of this ambiguity stems from the fact that the DT process does not have a set of rules, a single solution, or even a single expected outcome (Kane *et al*., 2019). This aforementioned milieu appears to be especially nettlesome to small and medium-sized retailers (SMRs). For instance, they tend to believe that DT is too complicated and costly, as well as unlikely to generate a favorable return on investment (Van Dyk & Van Belle, 2019).

However, there are currently no established business models or organizational "best" practices that companies can adopt to ensure success through the DT process (Saarikko *et al*., 2020; Savastano *et al*., 2022). This explains why the failure rate of enterprises undergoing DT is as high as 87.5%—due to unrealistic expectations, limited scope, and poor governance (Wade & Shan, 2020)—as little is known about how DT works (Kraft *et al*., 2022). As a result, these realities likely elevate SMRs' concerns and frustrations because there is a proven approach to the DT process.

Notwithstanding the challenges of the DT process, SMRs that are successful in implementing various technologies experience significant financial and operational rewards (Anthony *et al*., 2019). For this reason, how management decides to allocate its resources has become an important issue if a firm plans to pursue digital transformation (Li *et al*., 2024). To accelerate the DT process in SMRs and reduce any attendant risk of failure in its implementation, this study integrated two Multi-Criteria Decision Making (MCDM) methods to evaluate objectively critical factors (CFs) affecting DT in such retail enterprises. Using the Technology-Organization-Environment (TOE) framework (Tornatzky *et al*., 1990), we reviewed the extant literature regarding the salient factors that have been found to impact DT; we did so to establish a factor hierarchy table and to determine the efficacy of this factor structure through expert interviews. Factor weights were found using Fuzzy Analytic Hierarchy Process (FAHP) (Van Laarhoven & Pedrycz, 1983). We next used the concept of acceptable advantages of VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Opricovic, 1998) to objectively determine the CFs. Lastly, we proffer a number of strategies for SMRs, DT solution providers, and relevant government agencies to accelerate the DT process among retailers.

2. LITERATURE REVIEW

Innovative business models arising from the adoption of digital technologies have fundamentally changed consumer expectations and behavior, putting enormous pressure on traditional players and disrupting numerous markets. At the corporate level, the capacity to deal with and leverage fast-growing innovative digital technologies has seemingly been insurmountable for some enterprises—such as SMRs—leading them to falter vis-à-vis adopters of such technologies. Failure of SMRs to engage DT—owing conceivably to its lack of prevalence among peer competitors whom to imitate, as well as the high costs and risks associated with it—likely leads them to experience adverse knock-on effects. Therefore, many studies have discussed the risks and adoptive factors of DT. These studies are reviewed in detail hereafter.

Companies that go through the DT process are often forced to re-examine how they do business (Li, 2020). To adjust to DT demands, a company may experience dramatic changes in its technology requirements, security protocols, legal issues, talent capacity, competitors' actions, and unintended market responses to its product offerings. At the same time, when responding to DT changes, companies need to modify their management structure and organizational culture as well as enhance their internal propensity to and capability for digitalization. In their study, Nicolás-Agustín *et al*. (2022) found that, to some extent, human resource (HR) practices moderate the relationship between strategic alignment and DT. They also observed that companies should implement HR practices that encourage the alignment of employee behavior with organizational strategy in order to produce superior performance in DT. In another study, AlNuaimi *et al*. (2022) determined that DT leadership and organizational agility have a positive impact on DT and DT leadership also affects organizational agility. Furthermore, Nasiri *et al*. (2022) identified digital maturity as a mediator between digital orientation and firm financial success and between digital intensity and firm financial success. And finally, Mendes *et al*. (2022) exposited eight factors—economy, government, sustainability, infrastructure, technology, cooperation, change, and personnel/knowledge/skills—that affect the willingness and success of DT of enterprises.

The retail industry is thus not immune to issues that arise during the DT process, such as adaptation to new technologies, data privacy issues, customer experience, competitive pressure, and employee training. Perhaps most significantly, when competitors digitalize aspects of their operations, a retailer may be forced to make significant changes within their organization (e.g., development of new products, services, processes) in order to compete (Endres *et al*., 2021). This usually necessitates the commitment of financial and human capital just to ensure that aspects of the DT process can be implemented. In their study, Lokuge *et al*. (2019) proposed an Organizational Readiness for Digital Innovation (ORDI) construct that includes seven factors that are needed for the successful implementation of digital innovation. These factors are resource readiness, IT readiness, cognitive readiness, partnership readiness, cultural readiness, strategic readiness and innovation valence. Retailers that neglect one or more of these readiness factors will likely slow down the diffusion rate of any new technologies.

In the past, research dealing with the implementation of digital technologies has been conducted on large corporations (Cenamor *et al*., 2019) and on innovative firms, digital startups, and high-tech giants (Ghezzi & Cavallo, 2020). However, only a few studies have focused on the adoption of digital technologies by SMEs and micro-enterprises. Past research has often focused only on the digital transformation models of medium and large enterprises. Li (2020) observed that a group of global digital leaders at the forefront of digital transformation (including Amazon, Alibaba, Baidu, Google, JD.com, Uber, VMware, and Slack) have achieved success in digital transformation by (1) innovating through experimentation; (2) undergoing radical transformation through continuous and gradual changes; and (3) gaining dynamic and sustainable advantages through constantly evolving combinations of temporary advantages. Notably, the challenge for the retail industry in implementing such DT strategies is its more limited human and financial resources.

To be of singular value, research on the development of DT should be comprehensive, and it should be implemented from multiple perspectives, such as technology, organization, and environment (Song *et al*., 2022; He *et al*., 2024; Leso *et al*., 2024). Through its application, Tornatzky *et al*. (1990) TOE framework can help companies improve the planning and execution of DT strategies. Therefore, research on CFs has usually used the TOE framework as a research tool (Baker, 2021). Although scholars have chiefly employed TOE as their theoretical basis, they have tended to embrace the technology acceptance model (TAM) or structure equation modeling (SEM) plus the TOE framework when investigating CFs.

Our review of the foregoing studies revealed two key gaps in the DT literature. One pertains to the need to identify the CFs and their importance (i.e., weight). The second revolves around the issue that CFs entail an MCDM problem. Most extant work has utilized multiple regression analysis or SEM to uncover the CFs. Although the β value of multiple regression analysis or SEM can represent the importance (or weight) of the factors, errors or collinearity problems may occur when estimating it (Hair *et al*., 2009). Moreover, the identification of the CFs in existing investigations has been mainly based on the subjective judgment of the researcher, so the objectivity of that identification can be readily challenged. Furthermore, the use of multiple regression analysis or SEM in prior work has been limited by its theoretical model and thus has been unable to explore multiple factors concurrently. A crucial requirement when ascertaining CFs is to extract several CFs based on their importance among multiple influencing factors. Finding a few CFs from a broad set of factors may be more comprehensive than finding a few CFs from a small set of factors.

Past research, particularly that employing the TOE (Technology-Organization-Environment) framework (Baker, 2021), emphasizes that driving factors do not exist in isolation but rather form a systemic network. As past research has pointed out, external driving factors, such as competitive pressures from peers and customer demands (Ashton *et al*., 2017; AlNuaimi *et al*., 2022), generate the need for change. However, these demands are often constrained by internal driving factors, such as the adequacy of organizational resources and the support of senior management. During the digital transformation process, a lack of high-level support and environmental pressures can lead to "strategic anxiety" rather than genuine transformation. Technology in digital transformation is often an enabler rather than the primary driver. While digital infrastructure is a prerequisite, the adoption of technology may be impeded by a lack of resources or sustained motivation; therefore, the adoption of technology still requires the cooperation of the organization and the environment. The digital transformation (DT) of small and medium-sized retailers (SMRs) is chaotic and complex, with intricate interactions among its various drivers. These drivers often overlap but can also produce mutually exclusive effects. The motivation for adopting the hybrid FAHP-VIKOR approach stems from the complexity, interdependence, and conflict of these drivers (Jing *et al*., 2024). Traditional linear models often fail to capture the interactions between these drivers. Integrating these two multi-criteria decision-making (MCDM) approaches allows researchers to move beyond simple identification and delve into the realm of strategy prioritization.

In this study, we attempt to overcome the aforementioned weaknesses of previous research. To do so, we adopted TOE as the theoretical framework and collected factors to construct a three-level factor table. We utilized the MCDM tool FAHP to determine the weight of each factor. Then, we applied the concept of acceptable advantage of VIKOR to objectively identify the CFs. According to Saaty (1980), the number of criteria for each level in the three-level factor hierarchy table should not exceed seven so as not to affect the consistency of the results. Therefore, based on our review of previous literature on factors affecting DT and information and communication technology innovation, we summarized the findings of our review into a hierarchical factor with three dimensions of TOE. The first layer was technology, organization, and environment in sequence. The second layer subdivided each facet of the target layer into three facets. Technological factors were divided into DT tools, trust in DT technology, and DT data. Organizational factors were categorized into organizational capabilities, organizational characteristics, and organizational support. Environmental factors were partitioned into macro environment, industrial environment, and business environment. Finally, the three-hierarchy layer was segmented into 27 factors as shown in Table 1.

Table 1. Three hierarchy factor table

Goal layer	Target layer	Criteria layer	References
Technology	DT tools	Technology usefulness	Tahar *et al*., 2020
		Technology ease of use	Iriani & Andjarwati, 2020
		Technology compatibility	Lokuge *et al*., 2019
	Trust of DT technology	System security	Li, 2020; Lu & Wu, 2024
		System integrity	Abosata *et al*., 2021
		System reliability	Li, 2020
	DT data	Data acquisition difficulty	Reinartz *et al*., 2019
		Data usefulness	Reinartz *et al*., 2019; Sharifi *et al*., 2025
		Data complexity	Parsons *et al*., 2011
Organizational	Organizational capability	Organizational dedicated departments	Singh *et al*., 2020
		Organizational innovation capability	Nilssen, 2019; Savastano *et al*., 2022
		Organizational cross-departmental engagement	Nicolás-Agustín *et al*., 2022
	Organizational characteristics	Organizational scale	Wade & Shan, 2020
		Organizational culture	Saarikko *et al*., 2020
		Organizational goals and vision	Wade & Shan, 2020
	Organizational support	Support from senior executives	AlNuaimi *et al*., 2022; Li *et al*., 2024
		Organizational investment resources	Nasiri *et al*., 2022
		Organizational acceptance	Mendes *et al*., 2022; Leso *et al*., 2024
Environment	Macro- environment	Laws and regulations	Li, 2020; Li *et al*., 2024
		digital infrastructure	Su *et al*., 2024
		government incentives	Mendes *et al*., 2022
	Industrial environment	Industry competitive pressure	Li, 2020
		Industrial intelligence mastery	Bouncken *et al*., 2021
		Industrial characteristics	Sundaram *et al*., 2020
	Business environment	Customer requests	AlNuaimi *et al*., 2022
		Establishment of differentiated capabilities	Saarikko *et al*., 2020
		Pressure from peer competition	Ashton *et al*., 2017

This study employed the literature review process recommended by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Parums, 2021). Literature was searched in the following databases: Web of Science (Thomson Reuters), Science Direct, MDPI, Emerald Insight, SSRN, Taylor & Francis, Google Scholar, etc. Researchers used Boolean logic for English literature searches, employing OR for similar terms and AND for key concepts. Based on the four main research objectives of this study, Digital Transformation, Technology, Organizational and Environment, the following keywords were set for the search:

(1) DT tools, Trust of DT technology, DT data (also including Technology usefulness, Technology ease of use, Technology compatibility, System security, System integrity, System reliability, Data acquisition difficulty, Data usefulness, Data complexity);

(2) Organizational capability, organizational characteristics, organizational support (also including Organizational dedicated departments, Organizational innovation capability, Organizational cross-departmental engagement, Organizational scale, organizational culture, Organizational goals and vision, Support from senior executives, Organizational investment resources, Organizational acceptance);

(3) Macro-environment, Industrial environment, Business environment (also including Laws and regulations, digital infrastructure, government incentives, Industry competitive pressure, Industrial intelligence mastery, Industrial characteristics, Customer requests, Establishment of differentiated capabilities, Pressure from peer competition).

The inclusion and exclusion criteria for this literature review are as follows. Inclusion criteria are:
(1) At least Digital Transformation, Technology, Organization and Environment;
(2) Research topics include Fuzzy Analytic Hierarchy Process and VIKOR;
(3) Research literature with qualitative or quantitative data analysis.

Exclusion criteria were:
(1) Non-research literature, such as books, reader reviews, editorial opinions, literature reviews, etc., that do not contain research data;
(2) Literature with only abstracts (e.g., conference papers);
(3) Literature that only discusses legal provisions. Using the established search strategy and the designated literature database, the initial search results were 563 articles. After removing 75 duplicate papers, the authors, from 488 papers, used a title and abstract screening process to exclude 391 papers that were irrelevant to the research topic, leaving 97 papers for full-text screening. The authors read the full text of the 97 papers, excluding 71 papers that did not meet the literature selection criteria, leaving 26 papers that matched the topic.

3. METHOD

As noted earlier, obtaining the CF weights is an MCDM problem. Among the MCDM tools for determining the weights, the analytic hierarchy process (AHP) is the most commonly used (Saaty, 1980). However, the AHP method also has some deficiencies; these include reliance on expert opinion, subjectivity of weight calculation, and lack of consideration of uncertainty and risk (Munier & Hontoria, 2021). To solve these problems, Van Laarhoven & Pedrycz (1983) introduced fuzziness into AHP and then proposed the fuzzy analytical hierarchy process (FAHP) to solve the problem that AHP cannot consider the fuzziness of human thinking. FAHP takes into account the uncertainty of the problem, multiple criteria, and opinions of expert decision makers—especially when there are a large number of decision criteria and alternatives. FAHP not only avoids the limitation wherein pairwise comparison values are too subjective, but it also addresses the issue concerning inaccurate results (Balamurugan & Ranjitharamasamy, 2023; Balamurugan & Ranjitharamasamy, 2024). Accordingly, we used FAHP to discern the factor weights.

Selecting CFs from many factors, however, is difficult, as some factors might have very similar weight values; therefore, we would have likely encountered challenges in readily choosing the CFs. Wu *et al.* (2009), however, have suggested that VIKOR can be used to resolve this difficulty. Given the aforementioned, we integrated two MCDM methods (FAHP and VIKOR) to evaluate the CFs. Chang *et al.* (2023) used eclectic theory as a framework. The fuzzy analytic hierarchy process (FAHP) and the concept of the VIKOR acceptable advantage were used to obtain the weights of the CFs and to identify the CFs objectively. The FAHP-VIKOR process is shown in Figure 1. Our research was conducted in seven steps, as described below.

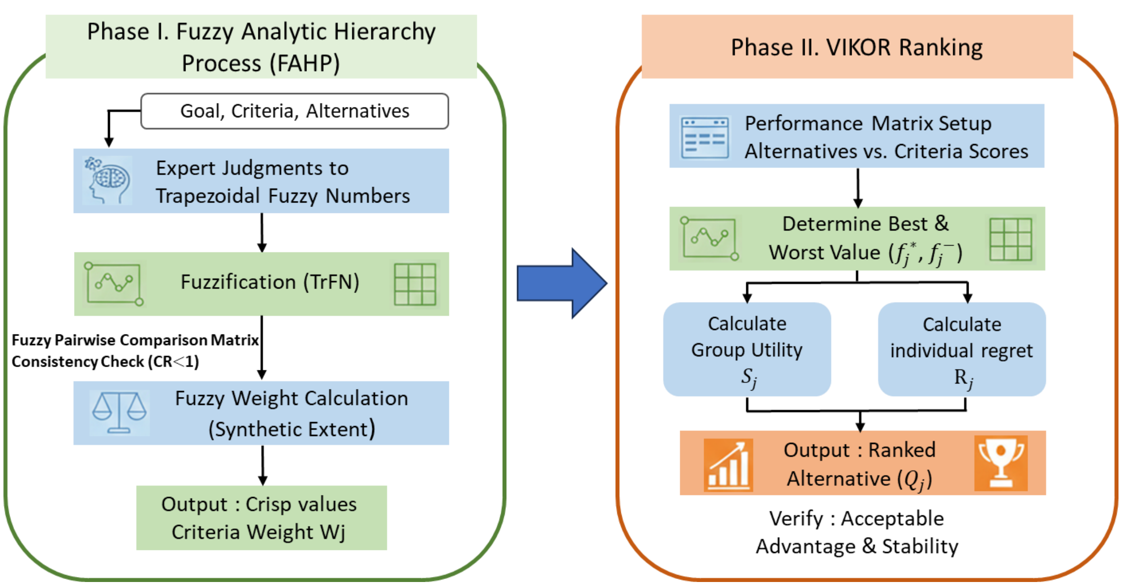

Figure 1. FAHP-VIKOR process

Step 1: Construct the hierarchical structure of elements and design expert questionnaires

A literature review on factors influencing DT adoption was undertaken. It revealed related factors influencing DT. These factors were then applied to the TOE framework to sort the factors, establish a hierarchical factor table, and design a survey to be distributed to experts.

Step 2: Establish fuzzy numbers

Generally speaking, there are two main methods to establish fuzzy numbers after the collection of questionnaires from experts. One is triangular fuzzy, and the other is trapezoidal fuzzy. Triangular fuzzy numbers may not be able to adequately capture the important factors that decision makers care about and are influenced by during decision-making. Therefore, such fuzzy numbers may lead to less accurate decision results (Dong *et al*., 2021). Compared with other fuzzy numbers, trapezoidal fuzzy numbers are more expressive; this is because they describe the degree of uncertainty of a variable and the distribution of uncertainty (Dombi & Jónás, 2020). Therefore, we used trapezoidal fuzzy numbers in this study. The following is the mathematical definition and formula explanation of trapezoidal fuzzy numbers.

(1) Definition of a Trapezoidal Fuzzy Number

A trapezoidal fuzzy number is typically represented as \widetilde{A}= (a, b, c, d), where a\le b\le c\le d. The four parameters represent:
a and b: the lower and upper bounds of the fuzzy number (the endpoints of the support set)
c and d: the intervals with a membership degree of 1 (the core part)

(2) Membership Function: Equation (1)

$$\text{Membership function } \mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \le x < b \\ 1, & b \le x \le c \\ \frac{d-x}{d-c}, & c < x \le d \\ 0, & x > d \end{cases} . \tag{1}$$

(3) Defuzzification

In FAHP, the trapezoidal ambiguity numbers ultimately need to be converted into sharp values (Crisp values) for sorting. The most commonly used method is the Centroid Method, and the commonly used deblurring Equation (2):

$$P(\tilde{A}) = \frac{a+2b+2c+d}{6}. \tag{2}$$

Step 3: Establish a fuzzy positive reciprocal matrix

Buckley (1985) averred that when calculating fuzzy weights, the column vector geometric mean method can be used. As such, the fuzzy weight of the fuzzy positive reciprocal matrix can be obtained, and the purpose of regularization can also be achieved. The method of establishing the positive reciprocal matrix through the trapezoidal fuzzy number is similar to the traditional AHP, but FAHP uses the vector method to represent the value in the matrix instead of the geometric mean. When the number of factors discussed is two, the matrix is 2x2; when the number of factors is three, it is 3x3; and so on. Therefore, the fuzzy positive reciprocal matrix can be constructed according to the definition of trapezoidal fuzzy numbers, and then the fuzzy weights can be obtained as noted below in Equation (3).

$$\text{Let } \overline{a_{ij}} = 1, \text{ when } i = j, \quad \overline{A} = \left[\overline{a_{ij}}\right] \tag{3}$$

where $\overline{a_{ij}} = (\alpha_{ij}, \beta_{ij}, \gamma_{ij}, \delta_{ij})$ When $i < j$ then $\overline{a_{ij}} = (\overline{a_{ji}}) - 1$, with $i > j$,
where $(\overline{a_{ji}}) - 1 = \left(\frac{1}{\delta_{ij}}, \frac{1}{\gamma_{ij}}, \frac{1}{\beta_{ij}}, \frac{1}{\alpha_{ij}}\right)$, I = 1, 2, 3, …, n. ; j =1, 2 , 3, …, n.

Step 4: Test Consistency

To judge whether the expert questionnaire was appropriate, we conducted the consistency test of the eigenvectors on the questionnaire results. Because the importance of the factors between each level is different, testing whether the entire hierarchy is consistent is necessary, as noted in Equation (4).

$$C.R. = C.I./R.I.;\ C.I. = (\lambda max - n)/(n-1) \quad (4)$$

CR is the Consistency Ratio, CI is the Consistency Index, and RI is the Random Index. After obtaining the CI and RI, CR can be calculated to test the consistency. Saaty (1980) suggested that CR ≤ 0.1 is the acceptable level, that λmax is to maximize the eigenvector of the pairwise comparison matrix, that n is the number of items in this matrix, and that RIn is a random index. All RIn values are shown in Table 2 (Aguarón & Moreno -Jiménez, 2003).

Table 2. Random Index table

n	3	4	5	6	7	8	9	10	11	12	13	14
RI_n	0.525	0.882	1.115	1.252	1.341	1.404	1.452	1.474	1.513	1.535	1.555	1.570

Step 5: Build the starting matrix

In the FAHP method, how to use the fuzzy positive reciprocal matrix established in the previous step is utilized to calculate the fuzzy weight. First, the fuzzy positive reciprocal matrix is employed as the starting matrix for operation, and the eigenvectors and eigenvalues of the starting matrix are obtained. Next, to convert these eigenvalues into comparable standardized values, standardization processing is required to obtain the standardized eigenvalues.

Step 6: Defuzzy number (α-cut)

This study used the α-cut and geometric mean to solve the fuzzy problem. Csutora & Buckley (2001) proposed the α-cut to determine the interval value of the fuzzy weight for each factor. This method has three advantages. First, it can handle any type of paired fuzzy numbers. Second, it does not need to be calculated, as only the vector value and eigenvalue of the positive matrix are needed. Third, compared with other methods, it can reduce ambiguity (Csutora & Buckley, 2001). After obtaining the fuzzy weight interval value of each factor (W*0l, W*1l, W*1u, W*0u) by using α-cut, the geometric mean is used to solve the fuzzy weight interval of each factor into a clear weight value (W*).

Step 7: Calculating the overall weights serially

After the weight calculation of each factor level is completed, the weight value is standardized to obtain the regional (i.e., local) weight, and then the regional weight values of different levels are concatenated to arrive at the global factor weight value. Next, the VIKOR indicator value (Q_j) is calculated using Equation (7). Sensitivity analysis is performed after the VIKOR ranking is completed. The \nu value is changed (from 0.1 to 0.9), or the criterion weights are adjusted, and the ranking is observed to see if there are any drastic changes. If not, it means that the ranking results of the factors are stable and reliable.

(1) Determine the best f_j^\ast and the worst f_j^- values of all criterion functions, i = 1, 2,...,n;

$$f_j^* = \max_j f_{ij},\ f_j^- = \min_j f_{ij}, \text{ if the i-th function represents a benefit;}$$
$$f_j^* = \min_j f_{ij},\ f_j^- = \max_j f_{ij}, \textit{ if the i-th function represents a cost;}$$

(2) Compute the values Sj and Rj, j = 1, 2,...,J, by the relations

$$S_j = \sum_{i=1}^{n} w_i \frac{f_i^* - f_{ij}}{f_i^{*-} - f_i^-}, \quad (5)$$

$$R_j = \max_i \left[w_i \frac{f_j^* - f_{ij}}{f_i^{*-} - f_i^-} \right], \quad (6)$$

where w_i are the weights of criteria, expressing the DM's preference as the relative importance of the criteria.

(3) Compute the values Q_j, j = 1, 2,...,J, by the relation

$$Q_j = \nu \frac{S_j - S^*}{S^- - S^*} + (1-\nu) \frac{R_j - R^*}{R^- - R^*}, \tag{7}$$

where S^*=$\min_j S_j$, S^-=$\max_j S_j$, R^*=$\min_j R_j$, R^-=$\max_j R_j$; and ν is introduced as a weight for the strategy of maximum group utility, whereas 1-ν is the weight of the individual regret.

(4) Rank the alternatives, sorting by the values S, R and Q in decreasing order. The results are three ranking lists.

Step 8: Determine CFs

Propose as a compromise solution the alternative ($A^{(1)}$) which is the best ranked by the measure Q (minimum) if the following two conditions are satisfied:

C1. Acceptable advantage:

$Q(A^{(2)}) - Q(A^{(1)}) \geq DQ,$ where $A^{(2)}$ is the alternative with second position in the ranking list by Q; DQ = 1/(J-1).

C2. Acceptable stability in decision making:

The alternative A^{(1)} must also be the best ranked by S or/and R. This compromise solution is stable within a decision-making process, which could be the strategy of maximum group utility (when \nu > 0.5 is needed), or "by consensus" \nu\approx0.5, or "with veto" (\nu<0.5). Here, \nu is the weight of decision making strategy of maximum group utility. If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of

- Alternatives $A^{(1)}$and $A^{(2)}$ if only the condition C2 is not satisfied, or
- Alternatives $A^{(1)}$, $A^{(2)}$,..., $A^{(M)}$ if the condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M (the positions of these alternatives are "in closeness").

The symbols used in the equation must be defined before the equation appears. Equations should be numbered consecutively, beginning with (1) to the end of the paper. The number should be enclosed in parentheses and set flush right in the column on the same line as the equation. An extra line of space should be left above and below a displayed equation or formula. Equation number should be right-justified. All the units used in this journal must follow Système International (SI) for units of measurement.

4. SURVEY OF EXPERTS

In this study, an expert questionnaire was designed to compare two factors based on the previous hierarchical structure table. It was emailed to experts in SMRs with the assistance of the chairman of the Association of Chain and Franchise Promotion, Taiwan. All 500 members in the association received the survey. A total of 44 questionnaires were returned. After the questionnaires were collected, we performed a consistency test on the questionnaires to confirm whether the results met the requirements for transferability. We confirmed that both the CI and CR values were less than 0.1, thus meeting the consistency principle. The final test results showed that 9 questionnaires did not meet the consistency requirement. Therefore, 35 valid questionnaires were used in our analyses.

Because FAHP is not based on statistical methods, its major advantage is that it does not require a large sample size. Therefore, its focus is on whether a sample correctly represents the overall image of the population, rather than whether there are enough sampling units (Duke & Aull-Hyde, 2002). Therefore, the FAHP sampling method involves intentional sampling. Intentional sampling is a non-probability sampling method that selects sample elements using the researcher's judgment. Researchers generally agree that a representative sample can be obtained through sound judgment, thus reducing time and cost (Black, 2010). Regarding the sample size for the expert questionnaire, Delbecq *et al*. (1975) stated that 15 to 30 is a reasonable sample size if the sample is highly homogeneous. The highly homogeneous 35 experts completing their questionnaires evinced such homogeneity.

4.1. Factor weights

Using the valid 35 questionnaires, the weights of factors at each level were calculated using the Excel software of FAHP, as shown in Table 3. The higher the weight, the greater the degree of influence. Conversely, the lower the weight, the less the degree of influence; factors in brackets are the order of importance.

Table 3. Overall weights of hierarchy table factors

A Goal layer weights	B Criteria layer weights	C=A×B	Sub-criteria layer	D Sub-criteria layer weights	E=C×D	Ranking
Technology 0.1939	DT tools 0.3009	0.0583	Technology usefulness	0.2425	0.0141	23
			Technology ease of use	0.4708	0.0274	15
			Technology compatibility	0.2865	0.0167	22
	Trust of DT technology 0.4706	0.0912	System security	0.4923	0.0448	10
			System integrity	0.1337	0.0121	25
			System reliability	0.3738	0.0340	13
	DT data 0.2283	0.044	Difficulty of obtaining data	0.2876	0.0126	24
			Data usefulness	0.5290	0.0232	17
			Data complexity	0.1832	0.0080	26
Organizational 0.3033	Organizational capability 0.2368	0.0718	The establishment of a dedicated department	0.2463	0.0177	21
			Organizational innovation capability	0.3159	0.0226	18
			Organizational cross-departmental engagement	0.4376	0.0314	14
	Organizational characteristics 0.1622	0.0491	Organizational scale	0.1412	0.0069	27
			Organizational Culture	0.4129	0.0202	20
			Organizational goals and vision	0.4458	0.0218	19
	Organizational support 0.6008	0.1822	Support from Senior Executive	0.4563	0.0831	2
			Organizational resources	0.3126	0.0569	5
			Organizational acceptance	0.2309	0.0420	11
Environment 0.5027	Macro environment 0.2989	0.1502	Laws and regulations	0.3723	0.0559	7
			Digital infrastructure	0.3926	0.0589	4
			Government incentives	0.2350	0.0352	12
	Industrial environment 0.2596	0.1305	Industry competitive pressure	0.3642	0.0475	9
			Industrial intelligence mastery	0.2053	0.0267	16
			Industrial characteristics	0.4303	0.0561	6
	Business environment 0.4413	0.2218	Customer requests	0.2425	0.0537	8
			Establishment of differentiation capabilities	0.4708	0.1044	1
			Pressure from peer competition	0.2865	0.0635	3

This research provides a systematic behavioral analysis of the driving factors behind Digital Transformation (DT) in Taiwanese Small and Medium-sized Retailers (SMRs). Compared to similar economies, the drivers in the Taiwanese context exhibit unique behavioral patterns, primarily characterized by the fact that environmental factors and organizational support hold significantly greater weight than purely technical considerations. Please see the Hierarchical TOE Framework of Digital Transformation Drivers (Figure 2). The following sections detail the specific systematic behavioral differences of the driving factors in Taiwan:

(1) Precedence of Environmental Drivers over Technological Drivers (Environment over Technology). In most global economic studies on DT, technological maturity or system security are typically viewed as core catalysts. However, within the systemic behavior of Taiwanese SMRs, the "Environment" emerges as the most powerful driver. Because the

Taiwanese retail market is hyper-saturated and intensely competitive, enterprises do not adopt digitalization merely for technical upgrades; rather, DT is perceived as a "survival strategy." Consequently, the ability to establish "differentiation capabilities" carries the highest weight (0.1044, ranked 1st) to ensure competitive advantages in a crowded market. Furthermore, pressure from peer competition and customer requests (ranked 3rd and 8th, respectively) compel a systemic response. This suggests that transformation in Taiwanese firms is often a reactive response to external environmental shifts rather than a proactive predisposition toward technological innovation.

(2) Management Support as the Strategic Pivot (Management as the Pivot): While DT in many developed economies may be initiated by technical pushes from IT departments, in Taiwan, " Support from Senior Executives" (ranked 2nd) serves as the central pivot for success. Since Taiwanese SMRs generally face resource constraints, DT is viewed as a high-risk decision. Without explicit support and involvement from senior leadership, the transformation system often stagnates due to internal cultural resistance and inertia. Additionally, "Resource Allocation" (ranked 5th) is prioritized over specific technology selection, indicating that the key to successful transformation in Taiwan lies in how internal resources are mobilized to align with environmental demands and digital needs.

(3) Macro-environmental Dependency: The analysis reveals a high sensitivity toward external public infrastructure and legal frameworks. This underscores the vital role of the government, as "Digital infrastructure" (ranked 4th) and "Laws and Regulations" (ranked 7th) are identified as critical factors. Taiwanese SMRs tend to initiate transformation only within a "stable and legal framework." Given that Taiwanese SMRs generally experience "anxiety" and perceive "prohibitive costs" regarding DT, government subsidies, incentives, and clear regulatory guidelines are essential to lowering perceived systemic risks, serving as a necessary prerequisite for progress.

Compared with similar economies, the DT driver system of Taiwanese SMRs is characterized by external pressures driving internal commitment. While technical attributes (such as system security or ease of use) are important, they do not occupy the most critical tier in the system hierarchy. Taiwanese enterprises place greater emphasis on whether the transformation can yield a competitive market advantage and whether leadership is willing to commit resources to meet external environmental challenges.

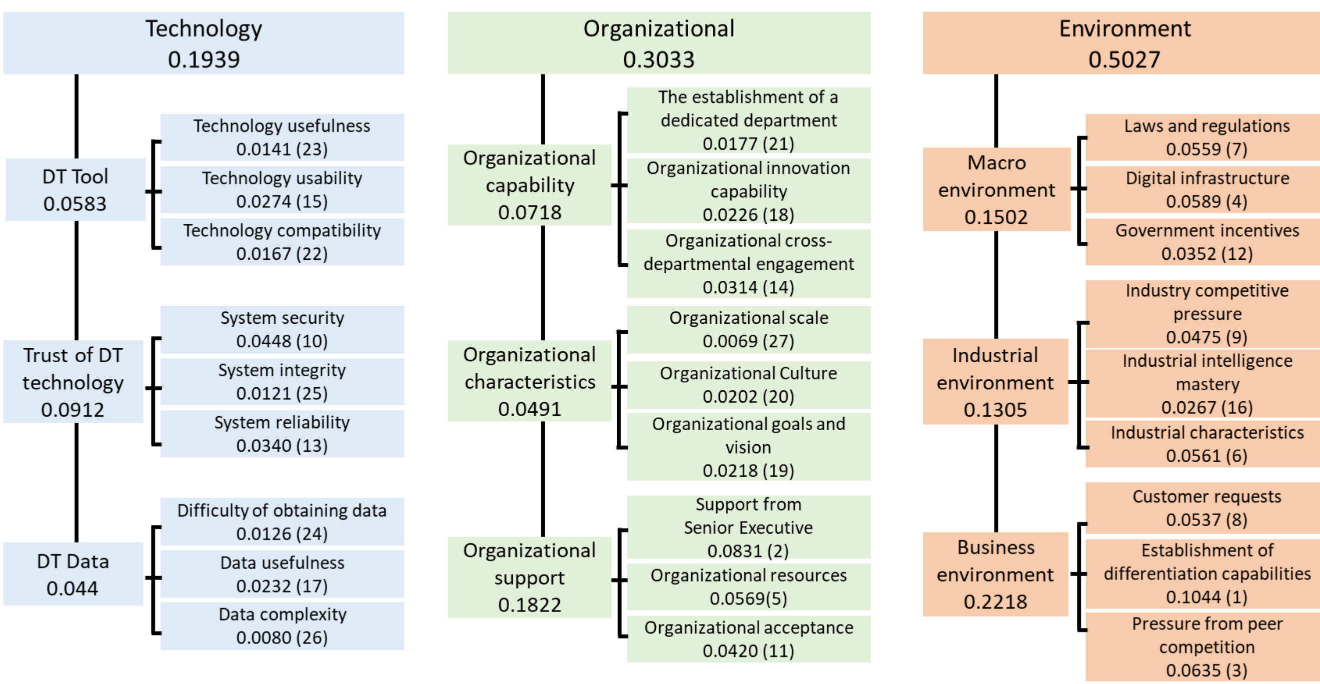

Figure 2. Hierarchical TOE Framework of Digital Transformation Drivers

4.2. Identification of CFs

The purpose of VIKOR's concept of acceptable advantages is to identify a set of feasible solutions gradually (based on Table 3). To avoid too many extraction steps, the CFs must be ranked prior to the importance of the factors. As such, 14 important factors (with weights greater than 0.03) were identified. The remaining 13 secondary factors. Next, we applied the VIKOR acceptable advantage concept to extract CFs from important factors. We first determined the break value through the following equation: i=1…n, for example, the break value (2) = (0.1044 − 0.0831)/(0.1044 − 0.0314) = 0.2918. Through this process, the break values for all 14 alternatives were obtained (Table 4).

Daniel (1961) argued that most industries have three to six CFs. However, Fu *et al*. (2022) reviewed the literature on CFs and noted that the CFs obtained in most studies have been between four and six. Therefore, in this study, VIKOR's concept of acceptable preponderance was used in the process of identifying CFs to stop the extraction process immediately after more than four CFs were identified and their cumulative weight exceeded 50% (Hsu *et al*., 2020). When four CFs were not measured, and the cumulative weight did not exceed 50%, extraction continued.

Table 4. Extraction process of VIKOR

Sub-criteria	**weights**	**1st Extraction**			**2nd Extraction**			**3rd Extraction**			**4th Extraction**		
		Break value	**TD**	**TD ≥ DQ**	**Break value**	**TD**	**TD ≥ DQ**	**Break value**	**TD**	**TD ≥ DQ**	**Break value**	**TD**	**TD ≥ DQ**
Establishment of differentiation capabilities	0.1044	0.0000	0.2918	Yes									
Support from Senior Executives	0.0831	0.2918	0.2685	Yes									
Pressure from peer competition	0.0635	0.5603	0.0630	No	0.0000	0.1433	yes						
Digital infrastructure	0.0589	0.6233	0.0274		0.1433	0.0623	no	0.0000	0.0727	No			
Organizational resources	0.0569	0.6507	0.0110		0.2056	0.0249		0.0727	0.0291		0.0000	0.0314	No
Industrial characteristics	0.0561	0.6616	0.0027		0.2305	0.0062		0.1018	0.0073		0.0314	0.0078	
Laws and regulations	0.0559	0.6644	0.0301		0.2368	0.0685		0.1091	0.0800		0.0392	0.0863	
Customer requests	0.0537	0.6945	0.0849		0.3053	0.1931		0.1891	0.2255		0.1255	0.2431	
Industry competitive pressure	0.0475	0.7795	0.0370		0.4984	0.0841		0.4145	0.0982		0.3686	0.1059	
System security	0.0448	0.8164	0.0384		0.5826	0.0872		0.5127	0.1018		0.4745	0.1098	
Organizational acceptance	0.042	0.8548	0.0932		0.6698	0.2118		0.6145	0.2473		0.5843	0.2667	
Government incentives	0.0352	0.9479	0.0164		0.8816	0.0374		0.8618	0.0436		0.8510	0.0471	
System reliability	0.034	0.9644	0.0356		0.9190	0.0810		0.9055	0.0945		0.8980	0.1020	
Organizational cross-departmental engagement	0.0314	1.0000			1.0000			1.0000			1.0000		
DQ=1/n		DQ=1/14=0.0714			DQ=1/12=0.0833			DQ=1/11=0.0909			DQ=1/10=0.1000		

Sub-criteria	**weights**	**5th Extraction**			**6th Extraction**			**7th Extraction**		
		Break value	**TD**	**TD ≥ DQ**	**Break value**	**TD**	**TD ≥ DQ**	**Break value**	**TD**	**TD ≥ DQ**
Establishment of differentiation capabilities	0.1044									
Support from Senior Executives	0.0831									
Pressure from peer competition	0.0635									
Digital infrastructure	0.0589									Yes

Sub-criteria	weights	5th Extraction			6th Extraction			7th Extraction		
		Break value	TD	TD ≥ DQ	Break value	TD	TD ≥ DQ	Break value	TD	TD ≥ DQ
Organizational resources	0.0569									Yes
Industrial characteristics	0.0561	0.0000	0.0081	No						Yes
Laws and regulations	0.0559	0.0081	0.0891		0.0000	0.0898	No			Yes
Customer requests	0.0537	0.0972	0.2510		0.0898	0.2531		0.0000	0.2780	Yes
Industry competitive pressure	0.0475	0.3482	0.1093		0.3429	0.1102		0.2780	0.1211	No
System security	0.0448	0.4575	0.1134		0.4531	0.1143		0.3991	0.1256	
Organizational acceptance	0.042	0.5709	0.2753		0.5673	0.2776		0.5247	0.3049	
Government incentives	0.0352	0.8462	0.0486		0.8449	0.0490		0.8296	0.0538	
System reliability	0.034	0.8947	0.1053		0.8939	0.1061		0.8834	0.1166	
Organizational cross-departmental engagement	0.0314	1.0000			1.0000			1.0000		
DQ=1/n		DQ=1/9=0.1111			DQ=1/8=0.125			DQ=1/7=0.143		

From this extraction process, we found in the first extraction that two factors, TD ≥ DQ, so two CFs were extracted, but less than four CFs emerged, and their cumulative weight did not exceed 50%. Therefore, a second extraction was performed with an additional extraction of one CF. The second extraction produced three CFs, with a cumulative weight of 25.1%, not exceeding 50%. The third, fourth, fifth and sixth extractions were subsequently performed, but no CF was extracted because TD < DQ. This meant that the importance of the 4th to 7th factors was very similar and needed to be extracted concurrently as the next one. So, the seventh extraction found a CF (TD ≥ DQ); this inferred that the importance of the 5th to the 8th was very close to being extracted at the same time, so five CFs were extracted. A total of eight CFs were extracted through six extractions, with a cumulative weight of 53.25%, thus satisfying the cumulative weight of more than 50%. Although these eight CFs exceeded the principle of four to six, the weight difference of the four CFs obtained in the third to sixth extraction was very close, judging whether there was a significant difference in the weight difference was difficult to ascertain; this implied that these four factors should have been extracted together. Therefore, a total of eight CFs was obtained: establishment of differentiated capabilities (0.1044), support from senior executives (0.0831), pressure from peer competition (0.0635), digital infrastructure (0.0589), organizational resources (0.0569), industry characteristics (0.0561), laws and regulations (0.0559) and customer requests (0.0537). Figure 3 shows the cumulative weights of 27 Digital Transformation drivers.

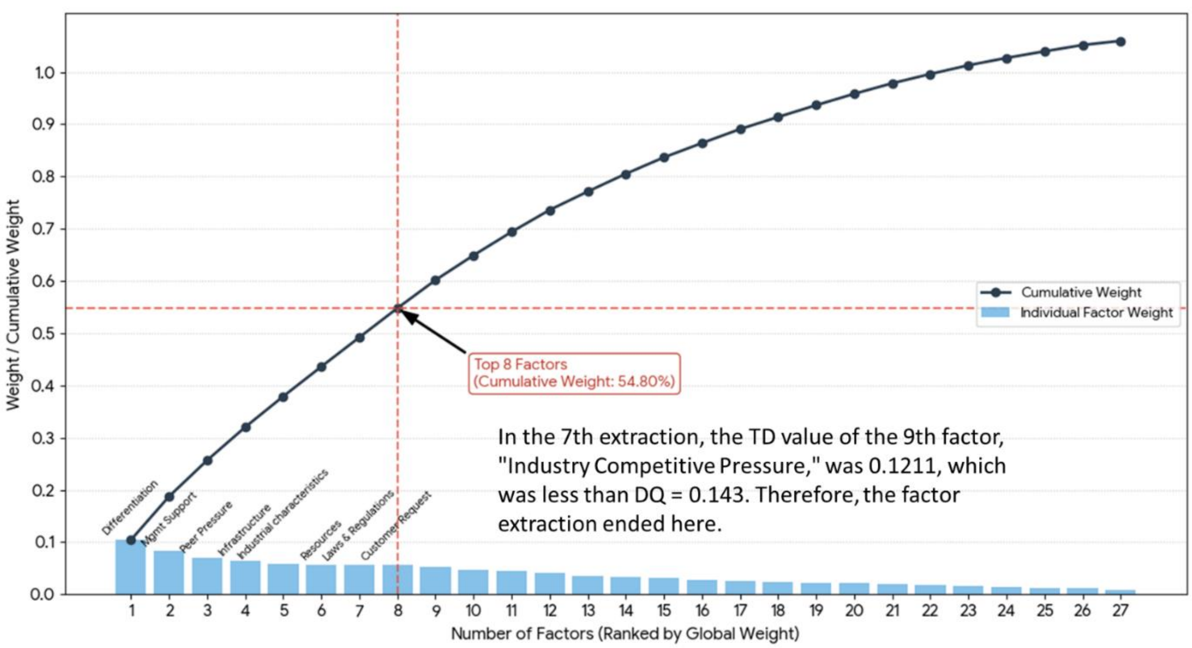

Figure 3. Cumulative Weights of Digital Transformation Drivers (27 factors)

5. DISCUSSION

5.1. CFs ANALYSIS

Using the acceptable advantage concept of VIKOR, eight key factors were extracted using the opinions of experts from SMRs in Taiwan. These findings emerged when considering DT through six extractions. Below, we discuss the key results vis-à-vis SMRs.

Establishment of differentiation capabilities. SMR executives believe that building differentiated capabilities is the most important CF in DT. Moreover, the establishment of differentiated capabilities can also help SMRs develop new products and services to meet the dynamic needs of their customers, thus potentially augmenting market share and profit. Developing differentiated competitiveness can be facilitated through a firm's internal planning in order to foster employee engagement, DT stability, and technological consistency (Saarikko *et al*., 2020). Support from senior executives. When introducing DT, strong support from top management during a major change in a company (such as DT) induces subordinates to invest time and energy into the change and to take risks. Because top executives have the resources and ultimate decision-making power, they must motivate team members to embrace DT changes, facilitate the development of DT skills, and influence employees' attitudes and decisions toward the DT process (Reis *et al*. 2018).

Pressure from peer competition. Competitive peer pressure plays an important role in stimulating innovation, improving efficiency, ameliorating products and services, enhancing the overall level of the industry, and promoting market development. These issues likely to arise when introducing DT into a company. The resource-constrained transformation of SMRs is mainly due to reduced internal motivation owing to high cost and keen competition, rather than from the external motivation of social responsibility considerations (Ashton *et al*., 2017). Therefore, SMRs usually face pressures to imitate their competitors rather than to beat these competitors.

Digital infrastructure. According to findings from Chawla & Goyal's (2021) analysis of 18 studies that examined the impact of DT on organizations, applications and insights, operational processes, and social aspects, digital infrastructure construction is considered critical for DT success. However, the internal information infrastructure of SMRs tends to be relatively weak due to the maturity of their internal information capacities and the readiness of their personnel to launch and use DT. Consequently, this may militate against SMR's use of DT.

Organizational resources. Improvement in service quality and customer satisfaction through DT is usually related to product innovation. However, resources must be invested with circumspection and on a relative basis—especially human and financial resources, which tend to be the weakest part of SMRs. This issue is one of the CFs for the DT in SMRs. This seemingly is because SMRs attach marked importance to DT's return on investment and whether there is assistance from the government or from other external sources, from which they might reduce use of their own internal resources if they introduce DT.

Industry characteristics. Industry characteristic has been identified as one of the CFs for DT in this paper. Industrial characteristics are one of the factors that enterprises must consider when implementing DT. Industrial characteristics affect such factors such as an enterprise's business model, competitive strategy, and customer needs; these, in turn, influence the success during the DT process. Vial (2021) mentioned that understanding the industrial characteristics of DT is crucial for introducing DT.

Laws and regulations. Laws and regulations include intellectual property rights, personal data protection, consumer protection, etc. Relevant laws and regulations can avoid other issues related to regulatory differences between countries, in order to promote the cross-border flow of knowledge and services (Jouanjean *et al*., 2020). In short, laws and regulations are a CF for DT in SMRs as these require SMRs to improve security measures (privacy and security of personal information), meet mobile payment needs, and ensure interface accessibility.

Customer requests. DT is related to customer needs, domain knowledge, and value dissemination. That is, when customers expect to manage the entire supply chain process, managing these functions becomes impossible in a firm without applications for DT (Andiyappillai, 2020). Therefore, the competitive environment of that firm is likely to be fierce, so retaining customers should be the focus of the company. Therefore, customer requirements can further drive the development of DT in organizations. Indeed, customer requirements are one of the important driving factors for implementing DT.

5.2. Managerial and Policy Implications

The findings of our study offer managerial implications for SMRs as well as for government agencies. These implications flow from the eight CFs that were revealed in this study.

First, the environmental context is critical for SMRs throughout the DT process. Among eight CFs, five belong to the environmental context, and two belong to the organizational context. This indicates that adjustments to the environmental context are foundational to the successful implementation of a new technology. And by implication, technology should not be the main driver of DT for SMRs. Instead, organizations should focus on the critical factors (i.e., establishment of differentiation capabilities, pressure from peer competition, digital infrastructure, industry characteristics, laws and regulations and customer requests) that ultimately determine the diffusion rate of digital technologies in SMRs. This seems to explain why many Taiwanese retailers still embrace a wait-and-see perspective concerning DT. While the environment acts as an external catalyst, prompting SMRs to initiate transformation for survival, the high weight of "digital transformation technology trust" (0.4706) indicates that technology plays a crucial internal filter or "gatekeeper" role in the transformation process. This subtle difference suggests that while external pressures dictate the necessity of corporate transformation, a lack of confidence in the reliability and security of technology remains a major psychological and operational obstacle to the transformation process. This orientation may be because the benefits of DT are not sufficiently clear, or because there are not many cases of successful DT in SMRs. Another possibility is that management continues to cling to a passive mentality: that is, they are waiting to face external environmental factors (e.g., changing customer requirements, threats from competitive peer pressure) before introducing DT. The nascent stage of SMRs' use of DT may necessitate government assistance in accelerating the employment of DT in SMRs.

Second, organizational executives need to "think and act" like entrepreneurs so that implementing digital technologies becomes more experimental in practice. For instance, an SMR can test the impact of a new technology in just one retail store to better understand some of the environmental and organizational issues that occur from introducing the technology. Of course, executives must continually keep up with changes in technology, industry, competition, customer needs, and the digital ecosystem. But employing a continuous improvement strategy that is rooted in this kind of experimentation process can help the SMR stay competitive and adapt to any requisite changes within its corporate culture. Continually experimenting with new ideas and strategies vis-à-vis transformations in the market and customer needs may conceivably assist in reducing risks. Furthermore, doing so might enable SMRs to adapt to market changes faster, sustain their competitive edge, and achieve long-term success.

SMRs tend to lack resources for promoting DT. SMRs require an increased willingness to invest in DT. However, they are prone to having insufficient resources to do so. An array of resources is needed for DT success. The resources required include material assets and manpower. In addition, senior executives' support and talent are requisite, but these are often scarce in SMRs. For example, few SMRs' executives have "technical vision and DT" and the ability to change, l*et al*one general talents. As such, if SMRs wish to introduce DT, they should cultivate the required DT skills in their executives. With strong support from top management for DT, subordinates should become more cognizant of how and where to invest time and energy in this change.

Finally, SMRs need to receive support from their respective governments. Currently, SMRs have little understanding of DT and the long-term benefits of implementing DTs. Government can play a key role in the guidance and facilitation of DT in SMRs. Efforts should include developing appropriate policies and regulations and providing relevant support and resources (e.g., a sound digital infrastructure) to promote DT in SMRs. In addition, the government can assist in the establishment of an expert advisory group to provide guidance and advice to SMRs; such a group could endeavor to improve DT skills and knowledge in such firms. The government could additionally seek to help SMRs address the challenges and problems associated with introducing DT.

5.3. Limitations and Future Study

This study has certain limitations. First, only SMRs in Taiwan were surveyed. However, due to geographical restrictions, different regions have different levels of digital infrastructure and informatization. Relatedly, culture varies across countries and regions. Therefore, our results may not be generalizable to other locales. Second, this study mainly focused on SMRs, but the research results may be different in different industries. We recommend additional in-depth research on DT. Scholars could consider undertaking investigations in various industries and in different countries and regions. Such studies should be conducted in industries having an array of industrial characteristics and scales.

6. CONCLUSION

The current perspective of Taiwanese SMRs concerning DT is influenced by many factors. Most of these SMRs remain on the sidelines, failing to introduce DT, or are passive about doing so. Therefore, successfully integrating DT technology into SMRs remains seemingly elusive. For this reason, to accelerate the introduction of DT in SMRs, we reviewed previous literature and identified 27 important factors vis-a-vis introduction of DT in such firms. We further sorted these 27 factors into a three-level factor hierarchy table and then applied the two MCDM tools of FAHP and VIKOR to extract eight CFs that need to be considered when introducing DT in SMRs. We also analyzed the various factors and then offered practical implications as a relevant reference for implementing DT in SMRs.

Our broad conclusion is that SMRs should design strategies, allocate resources, and avoid important failures when launching DTs. Our findings also provide DT solution providers with detailed information on SMR's predispositions toward DT, which should allow them to develop more effective implementation measures and to provide any necessary assistance during the DT process. Our results should also help government policy makers better understand the issues that are inhibiting the adoption of DT in SMRs. If a government opts to offer requisite support to SMRs, the risk of DT failure in SMRs may be reduced, and the introduction of DT in SMRs accelerated. Finally, it is important to note that our study only focused on SMRs in Taiwan. Additional studies are needed to better understand the critical factors (CFs) to the digital transformation process for retailers in other countries.

REFERENCES

Abosata, N., Al-Rubaye, S., Inalhan, G., & Emmanouilidis, C. (2021). Internet of things for system integrity: A comprehensive survey on security, attacks and countermeasures for industrial applications. *Sensors*, *21*(11), 3654. DOI: https://doi.org/10.3390/s21113654

Aguarón, J., & Moreno-Jiménez, J. M. (2003). The geometric consistency index: Approximated thresholds. *European journal of operational research*, *147*(1), 137-145. DOI: https://doi.org/10.1016/S0377-2217(02)00255-2

AlNuaimi, B. K., Singh, S. K., Ren, S., Budhwar, P., & Vorobyev, D. (2022). Mastering digital transformation: The nexus between leadership, agility, and digital strategy. *Journal of Business Research*, 145, 636-648. DOI: https://doi.org/10.1016/j.jbusres.2022.03.038

Andiyappillai, N. (2020). Digital transformation in warehouse management systems (WMS) implementations. *International Journal of Computer Applications*, 177(45), 34-37. DOI: https://doi.org/10.5120/ijca2020919957

Anthony, S. D., Trotter, A., & Schwartz, E. I. (2019). The top 20 business transformations of the last decade. *Harvard Business Review*.

Ashton, W., Russell, S., & Futch, E. (2017). The adoption of green business practices among small US Midwestern manufacturing enterprises. *Journal of environmental planning and management*, *60*(12), 2133-2149. DOI: https://doi.org/10.1080/09640568.2017.1281107

Baker, J. (2012). The technology–organization–environment framework. *Information Systems Theory: Explaining and Predicting Our Digital Society,* Vol. 1, 231-245. DOI: https://doi.org/10.1007/978-1-4419-6108-2_12

Balamurugan, A., & Ranjitharamasamy, S. P. (2023). A modified heuristics for the batch size optimization with combined time in a mass-customized manufacturing system. *International Journal of Industrial Engineering*, 30(5). DOI: https://doi.org/10.23055/ijietap.2023.30.5.9425

Balamurugan, A., & Ranjitharamasamy, S. P. (2024). Investigation of non-value-added activities to reduce lead time in the mass-customerized glass process industry. *International Journal of Industrial Engineering*, 31(5). DOI: https://doi.org/10.23055/ijietap.2024.31.5.9997

Black, K. (2010). Business Statistics: Contemporary Decision Making, 6th edn, John Wiley & Sons.

Bouncken, R. B., Kraus, S., & Roig-Tierno, N. (2021). Knowledge-and innovation-based business models for future growth: Digitalized business models and portfolio considerations. *Review of Managerial Science*, 15(1), 1-14. DOI: https://doi.org/10.1007/s11846-019-00366-z

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy sets and systems*, 17(3), 233-247. DOI: https://doi.org/10.1016/0165-0114(85)90090-9

Business Next (2023, March 15). *Taiwan's "Retail E-commerce Industry Structure" Annual Data Review*. Mira Business. Retrieved March 15, 2023, from https://www.bnext.com.tw/article/74110/retail-fl-230215

Cenamor, J., Parida, V., & Wincent, J. (2019). How entrepreneurial SMEs compete through digital platforms: The roles of digital platform capability, network capability and ambidexterity. *Journal of Business Research*, 100, 196-206. DOI: https://doi.org/10.1016/j.jbusres.2019.03.035

Chang, T. H., Yeh, W. C., Fu, H. P., & Teng, Y. H. (2023). A hybrid MCDM method to identify critical factors of foreign direct investment. *International Journal of Industrial Engineering*, 30(6). DOI: https://doi.org/10.23055/ijietap.2023.30.6.8509

Chawla, R. N., & Goyal, P. (2021). Emerging trends in digital transformation: a bibliometric analysis. *Benchmarking: An International Journal*, 29(4), 1069-1112. DOI: https://doi.org/10.1108/BIJ-01-2021-0009

Csutora, R., & Buckley, J. J. (2001). Fuzzy hierarchical analysis: the Lambda-Max method. *Fuzzy Sets and Systems*, 120(2), 181-195. DOI: https://doi.org/10.1016/S0165-0114(99)00155-4

Daniel, D.R. (1961). Management Information Crisis. *Harvard Business Review*, 39(5), 111-121.

Delbecq, A.L., Van de Ven, A.H. & Gustafson, D.H. (1975) Group Techniques for Program Planning: A Guide to Nominal Group and Delphi Processes. Scott, Foresman, Glenview, Illinois

Dombi, J., & Jónás, T. (2020). Ranking trapezoidal fuzzy numbers using a parametric relation pair. *Fuzzy sets and systems*, 399, 20-43. DOI: https://doi.org/10.1016/j.fss.2020.04.014

Dong, J., Wan, S., & Chen, S. M. (2021). Fuzzy best-worst method based on triangular fuzzy numbers for multi-criteria decision-making. *Information Sciences*, 547, 1080-1104. DOI: https://doi.org/10.1016/j.ins.2020.09.014

Duke, J. M., & Aull-Hyde, R. (2002). Identifying public preferences for land preservation using the analytic hierarchy process. *Ecological Economics*, 42(1-2), 131-145. DOI: https://doi.org/10.1016/S0921-8009(02)00053-8

Endres, H., Huesig, S., & Pesch, R. (2022). Digital innovation management for entrepreneurial ecosystems: services and functionalities as drivers of innovation management software adoption. *Review of Managerial Science*, 16(1), 135-156. DOI: https://doi.org/10.1007/s11846-021-00441-4

Fu, H. P., Chang, T. H., Lin, S. W., Teng, Y. H., & Huang, Y. Z. (2023). Evaluation and adoption of artificial intelligence in the retail industry. *International Journal of Retail & Distribution Management*, 51(6), 773-790. DOI: https://doi.org/10.1108/IJRDM-12-2021-0610

Ghezzi, A., & Cavallo, A. (2020). Agile business model innovation in digital entrepreneurship: Lean startup approaches. *Journal of Business Research*, 110, 519-537. DOI: https://doi.org/10.1016/j.jbusres.2018.06.013

Gong, C., & Ribiere, V. (2021). Developing a unified definition of digital transformation. *Technovation*, 102, 102217. DOI: https://doi.org/10.1016/j.technovation.2020.102217

Hair Jr, J. F., Black, W. C., & Babin, B. J. (2009). Multivariate Data Analysis. 7th ed. Upper Saddle River, NJ: Pearson Education

He, Q., Ribeiro-Navarrete, S., & Botella-Carrubi, D. (2024). A matter of motivation: the impact of enterprise digital transformation on green innovation. *Review of Managerial Science*, 18(5), 1489-1518. DOI: https://doi.org/10.1007/s11846-023-00665-6

Hsu, K. Y., Fu, H. P., Lin, A. J., & Ou, T. Y. (2020). Factor analysis of SMEs entering foreign markets: the case of Taiwanese SMEs in Vietnam. *European Journal of International Management*, 14(3), 524-550. DOI: https://doi.org/10.1504/EJIM.2020.107020

Iriani, S. S., & Andjarwati, A. L. (2020). Analysis of perceived usefulness, perceived ease of use, and perceived risk toward online shopping in the era of Covid-19 pandemic. *Systematic Reviews in Pharmacy*, 11(12), 313-320. DOI: https://doi.org/10.31838/srp.2020.12.50

Jackson, N. C. (2019). Managing for competency with innovation change in higher education: Examining the pitfalls and pivots of digital transformation. *Business Horizons*, 62(6), 761-772. DOI: https://doi.org/10.1016/j.bushor.2019.08.002

Jing, S., Hou, K., Zhanwen, N., & Yan, J. (2024). Advancing an evaluation model: how do family SMEs select innovation scheme in lean management?. *Soft Computing*, 28(5), 4125-4149. DOI: https://doi.org/10.1007/s00500-023-09389-x

Jouanjean, M. A., Casalini, F., Wiseman, L., & Gray, E. (2020). Issues around data governance in the digital transformation of agriculture: The farmers' perspective. OECD Food, Agriculture and Fisheries Papers No. 146, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/53ecf2ab-en

Kane, G. (2019). The technology fallacy: people are the real key to digital transformation. *Research-Technology Management*, 62(6), 44-49. DOI: https://doi.org/10.1080/08956308.2019.1661079

Kraft, C., Lindeque, J. P., & Peter, M. K. (2022). The digital transformation of Swiss small and medium-sized enterprises: insights from digital tool adoption. *Journal of Strategy and Management*, 15(3), 468-494. DOI: https://doi.org/10.1108/JSMA-02-2021-0063

Leso, B. H., Cortimiglia, M. N., Ghezzi, A., & Minatogawa, V. (2024). Exploring digital transformation capability via a blended perspective of dynamic capabilities and digital maturity: a pattern matching approach. *Review of Managerial Science*, 18(4), 1149-1187. DOI: https://doi.org/10.1007/s11846-023-00692-3

Li, B., Zheng, Y., Zheng, W., & Wu, Y. J. (2024). Effect of top management team attention to digital transformation on innovation activities. *Total Quality Management & Business Excellence*, *35*(13–14), 1640–1658. DOI: https://doi.org/10.1080/14783363.2024.2390535

Li, F. (2020). Leading digital transformation: three emerging approaches for managing the transition. *International Journal of Operations & Production Management*, 40(6), 809-817. DOI: https://doi.org/10.1108/IJOPM-04-2020-0202

Lokuge, S., Sedera, D., Grover, V., & Dongming, X. (2019). Organizational readiness for digital innovation: Development and empirical calibration of a construct. *Information & management*, 56(3), 445-461. DOI: https://doi.org/10.1016/j.im.2018.09.001

Lu, W., & Wu, L. (2024). A blockchain-based deployment framework for protecting building design intellectual property rights in collaborative digital environments. *Computers in Industry*, 159, 104098. DOI: https://doi.org/10.1016/j.compind.2024.104098.

Mendes, J. A. J., Carvalho, N. G. P., Mourarias, M. N., Careta, C. B., Zuin, V. G., & Gerolamo, M. C. (2022). Dimensions of digital transformation in the context of modern agriculture. *Sustainable Production and Consumption*, 34, 613-637. DOI: https://doi.org/10.1016/j.spc.2022.09.027

MOEA (2025, January 20). 2022 Statistics Annual Report. Department of Statistics, Ministry of Economic Affairs. Retrieved January 20, 2025, from https://www.moea.gov.tw/Mns/dos/content/ContentLink.aspx?menu_id=9432

Munier, N., & Hontoria, E. (2021). Shortcomings of the AHP Method. *Uses and Limitations of the AHP Method: A Non-Mathematical and Rational Analysis*, 41-90. DOI: https://doi.org/10.1007/978-3-030-60392-2_5

Nasiri, M., Saunila, M., & Ukko, J. (2022). Digital orientation, digital maturity, and digital intensity: determinants of financial success in digital transformation settings. *International Journal of Operations & Production Management*, 42(13), 274-298. DOI: https://doi.org/10.1108/IJOPM-09-2021-0616

Nicolás-Agustín, Á., Jiménez-Jiménez, D., & Maeso-Fernandez, F. (2022). The role of human resource practices in the implementation of digital transformation. *International Journal of Manpower*, 43(2), 395-410. DOI: https://doi.org/10.1108/IJM-03-2021-0176

Nilssen, M. (2019). To the smart city and beyond? Developing a typology of smart urban innovation. *Technological forecasting and social change*, 142, 98-104. DOI: https://doi.org/10.1016/j.techfore.2018.07.060

Opricovic, S. (1998). Multicriteria optimization of civil engineering systems. *Faculty of Civil Engineering, Belgrade*, 2(1), 5-21.

Parsons, M. A., Godøy, Ø., LeDrew, E., De Bruin, T. F., Danis, B., Tomlinson, S., & Carlson, D. (2011). A conceptual framework for managing very diverse data for complex, interdisciplinary science. *Journal of Information Science*, 37(6), 555-569. DOI: https://doi.org/10.1177/0165551511412705

Parums, D. V. (2021). Review articles, systematic reviews, meta-analyses, and the updated Preferred Reporting Items for systematic reviews and meta-analyses (PRISMA) 2020 guidelines. Medical Science Monitor: *International Medical Journal of Experimental and Clinical Research*, 27, e934475-1. DOI: https://doi.org/10.12659/MSM.934475

Ponsignon, F., Kleinhans, S., & Bressolles, G. (2019). The contribution of quality management to an organization's digital transformation: a qualitative study. *Total Quality Management & Business Excellence*, 30(sup1), S17–S34. DOI: https://doi.org/10.1080/14783363.2019.1665770

Reinartz, W., Wiegand, N., & Imschloss, M. (2019). The impact of digital transformation on the retailing value chain. *International Journal of Research in Marketing*, 36(3), 350-366. DOI: https://doi.org/10.1016/j.ijresmar.2018.12.002

Reis, J., Amorim, M., Melão, N., Matos, P. (2018). Digital Transformation: A Literature Review and Guidelines for Future Research. In: Rocha, Á., Adeli, H., Reis, L.P., Costanzo, S. (eds) Trends and Advances in Information Systems and Technologies. WorldCIST'18 2018. *Advances in Intelligent Systems and Computing*, vol 745. Springer, Cham. DOI: https://doi.org/10.1007/978-3-319-77703-0_41

Ruso, J., Milošević, I., Stojanović, A., Glogovac, M., Rakić, A., & Arsić, S. (2024). Regional variations in digital transformation: the impact of Industry 5.0 on business quality performance. *Total Quality Management & Business Excellence*, 35(15-16), 1879-1899. DOI: https://doi.org/10.1080/14783363.2024.2416171

Saarikko, T., Westergren, U. H., & Blomquist, T. (2020). Digital transformation: Five recommendations for the digitally conscious firm. *Business horizons*, 63(6), 825-839. DOI: https://doi.org/10.1016/j.bushor.2020.07.005

Savastano, M., Zentner, H., Spremić, M., & Cucari, N. (2022). Assessing the relationship between digital transformation and sustainable business excellence in a turbulent scenario. *Total Quality Management & Business Excellence*, 1–22. DOI: https://doi.org/10.1080/14783363.2022.2063717

Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York, McGraw-Hill

Sharifi, E., Chaudhuri, A., Farahani, S. D., Staal, L. G., & Waehrens, B. V. (2025). Virtual warehousing through digitalized inventory and on-demand manufacturing: A case study. *Computers in Industry*, 164, 104184. DOI: https://doi.org/10.1016/j.compind.2024.104184.

Singh, A., Klarner, P., & Hess, T. (2020). How do chief digital officers pursue digital transformation activities? The role of organization design parameters. *Long Range Planning*, *53*(3), 101890. DOI: https://doi.org/10.1016/j.lrp.2019.07.001

SMEA (2025, January 20). *2022 SME White Paper*. Small and Medium Enterprise Administration, Ministry of Economic Affairs. Retrieved January 20, 2025, from https://www.sme.gov.tw/list-tw-2345

Song, Y., Escobar, O., Arzubiaga, U., & De Massis, A. (2022). The digital transformation of a traditional market into an entrepreneurial ecosystem. *Review of Managerial Science*, *16*(1), 65-88. DOI: https://doi.org/10.1007/s11846-020-00438-5

Su, J., Liu, J., & Wang, S. (2024). A study on the action mechanism of digital transformation on the output quality of technological innovation. *Total Quality Management & Business Excellence*, *35*(3-4), 321-340. DOI: https://doi.org/10.1080/14783363.2023.2290651

Sundaram, R., Sharma, D. R., & Shakya, D. A. (2020). Digital transformation of business models: A systematic review of impact on revenue and supply chain. *International Journal of Management*, 11(5), 9-21. https://ssrn.com/abstract=3628963
Tahar, A., Riyadh, H. A., Sofyani, H., & Purnomo, W. E. (2020). Perceived ease of use, perceived usefulness, perceived security and intention to use e-filing: The role of technology readiness. *The Journal of Asian Finance, Economics and Business*, *7*(9), 537-547.

Tornatzky, L.G., Fleischer, M. and Chakrabarti, A.K. (1990). *The Processes of Technological Innovation* (Vol. 273). Lexington, MA: Lexington Books.

Van Dyk, R., & Van Belle, J. P. (2019). Factors influencing the intended adoption of digital transformation: A South African case study. In *2019, federated conference on Computer Science and Information Systems (FedCSIS)*. 519-528. IEEE. DOI: https://doi.org/10.15439/2019F166

Van Laarhoven, P. J., & Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems*, *11*(1-3), 229-241. DOI: https://doi.org/10.1016/S0165-0114(83)80082-7

Vial, G. (2021). Understanding digital transformation: A review and a research agenda. *The Journal of Strategic Information Systems*, 28(2), 118-144. DOI: https://doi.org/10.1016/j.jsis.2019.01.003

Wade, M., & Shan, J. (2020). COVID-19 has accelerated digital transformation, but may have made it harder not easier. *MIS Quarterly Executive*, *19*(3). From https://aisel.aisnet.org/misqe/vol19/iss3/7

Wu, H. Y., Tzeng, G. H., & Chen, Y. H. (2009). A fuzzy MCDM approach for evaluating banking performance based on Balanced Scorecard. *Expert systems with applications*, *36*(6), 10135-10147. DOI: https://doi.org/10.1016/j.eswa.2009.01.005