

Identifying and Prioritizing Critical Success Factors for Twin Transformation in Turkish SMEs: A Best-Worst Method Approach

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Abstract

The twin transformation, the simultaneous pursuit of digital and sustainable transformation, poses significant challenges for small and medium-sized enterprises (SMEs), yet structured approaches to prioritizing its critical success factors remain scarce, particularly in non-Western contexts. This study identifies and prioritizes nine critical success factors for twin transformation in Turkish SMEs, where SMEs constitute 99.7% of all enterprises. Factors were derived through a systematic literature review and Delphi-based expert consultation, then weighted using the Best-Worst Method (BWM) with three domain experts whose profiles span academic research, private sector experience, and sustainability consultancy. Results reveal a stratified priority structure in which Strategic Leadership and Management, Human Resources and Competencies, and Financial Resources and Investment Capacity emerge as the three most critical factors, collectively accounting for 46% of total weight, while Performance Management and Measurement and External Environment and Ecosystem received the lowest weights. The findings offer evidence-based guidance for SME managers, policymakers, and business support organizations navigating the twin transformation in resource-constrained environments.

Keywords

Twin Transformation, Digital Transformation, Sustainability, SMEs, Best-Worst Method.

1. Introduction

The rapid advancement of digital technologies is fundamentally reshaping industries worldwide, compelling businesses to reconsider their operational models, competitive strategies, and value creation mechanisms. Digital transformation (DT) has evolved from a competitive differentiator into an operational necessity, while simultaneously, mounting environmental concerns and regulatory pressures are pushing organizations to embed sustainability into

their core strategies (Hanelt et al. 2021; Kraus et al. 2021). The convergence of these two imperatives has given rise to the concept of "twin transformation," referring to the simultaneous and mutually reinforcing pursuit of digital and green transformation, in which digital capabilities enable environmental monitoring and resource optimization while sustainability objectives give direction to digital investment decisions (Isensee et al. 2020; Abilakimova et al. 2025; Ben Youssef 2025).

SMEs are central to most economies but the transformation challenges they face look nothing like those of large corporations. Operating under chronic constraints in financial resources, human capital, and digital infrastructure maturity, SMEs must simultaneously pursue digital and sustainability agendas within tightly bounded resource envelopes and with limited organizational slack (Philbin et al. 2022; Melo et al. 2023). The scholarly literature on twin transformation in SMEs has grown considerably, yet remains geographically and methodologically uneven. Existing studies have catalogued barriers and enablers across European manufacturing contexts (Abilakimova et al. 2025; Leipziger et al. 2025), identified leadership and culture as the most influential transformation dimensions (Ahmad et al. 2023; Ben Youssef 2025), and demonstrated that SMEs systematically lag behind larger enterprises across key digital and sustainability indicators (Burinskiene and Nalivaika 2024). Despite this progress, three gaps persist: the concentration of empirical work in European contexts leaves non-Western settings underexplored; the relative importance of identified factors remains poorly understood due to the scarcity of structured quantitative weighting approaches; and the translation of findings into context-specific priorities for SME practitioners is frequently absent.

Turkey presents a compelling context for addressing these gaps. As of the end of 2023, SMEs constitute 99.7% of all enterprises in Turkey's industrial and service sectors, totaling 3,713 million firms (TUIK 2024). The country's Eleventh Development Plan (2019–2023) identified digitalization in manufacturing as a strategic priority (Sirkintoğlu Yıldırım and Durukan 2023), and Turkey's alignment with European Green Deal objectives has intensified twin transformation pressures on domestic firms (Deniz 2025). No study has so far examined twin transformation success factors in the Turkish SME context through a structured multi-criteria weighting lens.

To address this gap, this study employs the Best-Worst Method (BWM), introduced by Rezaei (2015). Unlike the Analytic Hierarchy Process, BWM requires only $2n-3$ comparisons for n criteria, reducing cognitive burden while improving judgment consistency. Its quantifiable consistency ratio (ξ) enables transparent reliability assessment—particularly valuable when working with small expert panels (Rezaei 2015; Rezaei 2016; Mi et al. 2019). This study makes three contributions: extending twin transformation research to the Turkish SME context; applying BWM to produce quantitative factor prioritization; and grounding the factor set in systematic literature review complemented by Delphi-based expert consultation.

The primary objective of this study is to identify and prioritize the critical success factors influencing twin transformation in Turkish SMEs. Toward this overarching aim, the study pursues three specific objectives. First, a comprehensive set of candidate factors is derived through a systematic review of the twin transformation literature, supplemented by Delphi-based expert consultation to ensure that the identified factors reflect both theoretical grounding and practical relevance to the Turkish SME context. Second, the derived factors are evaluated by three domain experts whose profiles span academic research, private sector project experience, and sustainability consultancy, providing a multi-perspective assessment grounded in Turkish market realities. Third, the Best-Worst Method (BWM) is applied to calculate the relative weights and priority rankings of the identified factors, generating a structured and empirically grounded prioritization that moves beyond qualitative enumeration.

The remainder of this paper is structured as follows. Section 2 reviews the literature on twin transformation success factors. Section 3 describes the methodology, including factor derivation and BWM procedure. Section 4 presents the application of the methodology and resulting factor weights. Section 5 discusses the findings. Section 6 concludes with limitations and future research directions.

2. Literature Review

The relationship between digital transformation and sustainability in SMEs is increasingly understood as mutually reinforcing rather than competing. Philbin et al. (2022) demonstrated that DT supports sustainability outcomes through operational efficiency gains, business model innovation, and supply chain collaboration, identifying leadership,

culture, skills, and strategic alignment as the critical organizational bridges. Melo et al. (2023) found that integrated performance measurement tools capturing economic, environmental, and social dimensions simultaneously remain scarce despite accelerating Industry 4.0 adoption. Isensee et al. (2020) established that organizational culture plays a foundational role in determining whether digital investments produce sustainability gains or remain confined to efficiency improvements.

The simultaneous pursuit of digital and green transformation, theorized as "twin transformation", has emerged as a distinct research stream, primarily within European manufacturing contexts. Chatzistamoulou (2023), drawing on data from over 20,000 SMEs across 28 EU countries, provided econometric evidence that DT positively fosters sustainability outcomes, while institutional weaknesses such as business corruption significantly impede progress. Burinskiene and Nalivaike (2024) demonstrated that SMEs systematically lag behind larger enterprises across sixteen key digital and sustainability indicators. Abilakimova et al. (2025) identified 20 barriers and five enablers across micro, meso, and macro levels in European manufacturing SMEs, with awareness deficits, mindset rigidity, skills gaps, and high investment costs emerging as the most pervasive constraints.

At the firm level, Leipziger et al. (2025) identified seven dimensions functioning as barriers or enablers depending on organizational maturity, with corporate culture emerging as the most influential. Financial constraints, though prominent as early-stage barriers, tended to shift toward enablers as efficiency gains materialized. Ahmad et al. (2023) demonstrated that digital organizational culture moderates the relationship between CSR digitalization and sustainable competitive performance in Pakistani SMEs, while Rahnama et al. (2022) showed that collaborative rather than isolated approaches are essential for smaller firms navigating the twin transformation. Ben Youssef (2025), synthesizing perspectives across 27 countries, identified visionary leadership, workforce upskilling, and supportive innovation ecosystems as the most consistently cited success factors.

Within the Turkish context, Deniz (2025) identified meaningful progress in e-government, renewable energy, and circular economy initiatives alongside persistent challenges in regulatory predictability, green financing access, and skills infrastructure. Sirkintoğlu Yıldırım and Durukan (2023) found that KOSGEB support mechanisms enable digital transformation in manufacturing SMEs, though uptake remains uneven. Büyüközkan and Çelik (2025), applying an integrated SWOT-SWARA approach to the digital transformation of Turkish SMEs, identified economic fluctuations, financial constraints, cybersecurity risks, and Industry 4.0 readiness as critical factors, though the sustainability dimension and twin transformation framework were not addressed, leaving a consequential empirical gap.

The growing adoption of MCDM methods in transformation research reflects the need to move beyond qualitative cataloguing toward structured quantitative prioritization (Burinskiene and Nalivaike 2024). BWM, introduced by Rezaei (2015), has gained traction due to its reduced comparison requirements and built-in consistency verification. Mi et al. (2019) confirmed that BWM consistently produces more reliable weights than ratio-based alternatives such as SWARA. Collectively, the reviewed literature reveals three gaps, geographic concentration in European contexts, methodological reliance on qualitative approaches, and thematic fragmentation between digital and sustainability agendas in the Turkish setting, that the present study addresses simultaneously.

3. Methodology

This study adopts a structured expert-based research design that combines systematic literature review, Delphi-based expert consultation, and multi-criteria decision-making analysis to identify and prioritize the critical success factors for twin transformation in Turkish SMEs. The methodology unfolds across three sequential phases, as illustrated in Figure 1.

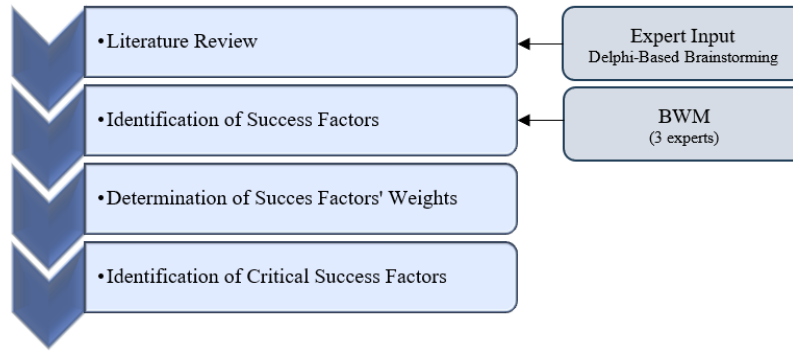


Figure 1. Research methodology flowchart

3.1. Factor Identification

The identification of candidate success factors followed a two-stage process designed to ensure both theoretical comprehensiveness and practical relevance. In the first stage, a systematic review of the twin transformation literature was conducted, drawing on peer-reviewed journal articles, conference proceedings, and policy reports published between 2015 and 2025. The review focused specifically on studies examining the enablers, barriers, and organizational prerequisites for digital and sustainability transformation in SMEs, with particular attention to factors that have been empirically validated or repeatedly identified across multiple independent studies. The initial pool of factors generated through this process was subsequently refined through a Delphi-based expert consultation, in which three domain experts with complementary backgrounds in the Turkish SME ecosystem reviewed, consolidated, and validated the candidate factors through iterative discussion. Factors were retained in the final set when expert consensus confirmed their relevance and distinctiveness within the Turkish SME context. This combined process yielded nine critical success factors, summarized in Table 1, which collectively span the technological, organizational, human, financial, and external dimensions of twin transformation.

3.2. Expert Profiles

The expert panel assembled for this study consists of three professionals whose backgrounds collectively cover the academic, private sector, and consultancy dimensions of twin transformation in Turkey. The first expert is a professor of industrial engineering at a leading Turkish university, with an established academic reputation and six years of focused research and applied work in digitalization, including active consultancy engagements with Turkish SMEs and collaborative industry-academia projects. The second expert holds an industrial engineering degree from a reputable Turkish university and has accumulated eight years of project-based professional experience in the private sector, working across both digital transformation and sustainability initiatives. The third expert is the owner of a consultancy firm with extensive experience delivering sustainability projects and advisory services to multiple firms across diverse sectors, and has more recently expanded this practice to encompass the digitalization of sustainability processes. Together, the three experts provide perspectives that span theoretical depth, operational project experience, and strategic consultancy practice, all grounded in direct engagement with the Turkish market.

3.3. Success Factors

The nine critical success factors derived through the combined literature review and expert consultation process are presented in Table 1. Each factor represents a distinct organizational or contextual dimension whose presence or absence has been shown to materially influence the likelihood of successful twin transformation in SMEs.

Table 1. Critical success factors for twin transformation in Turkish SMEs

Factor	Definition	Key References
F1. Digital Technology and Infrastructure	Capacity to adopt, integrate, and maintain the technological foundations required for transformation, including hardware, software, connectivity, cloud systems, IoT, ERP platforms, and sustainability-enabling tools.	Matt et al. (2015); Vial (2019); Hoang (2024); Ramirez-Orellana et al. (2024)

F2. Data Management and Analytical Capacity	Systematic collection, governance, processing, and interpretation of operational and sustainability-related data, and translation of analytical outputs into evidence-based decisions.	Mikalef et al. (2020); Kristoffersen et al. (2021); Al-khatib (2023); Akhtar et al. (2024)
F3. Strategic Leadership and Management	Coherent strategic vision for transformation, deliberate alignment of digital and sustainability objectives with organizational direction, and active mobilization of resources to sustain transformation commitments.	Rossato and Castellani (2020); Khaw et al. (2022); Samimi et al. (2022); Mollah et al. (2024)
F4. Human Resources and Competencies	Availability, quality, and ongoing development of human capital encompassing digital literacy, sustainability competencies, and the adaptive skills required to drive transformation.	Eller et al. (2020); Khan et al. (2023); OECD (2025)
F5. Organizational Culture and Change Readiness	Shared values, behavioral norms, and collective orientations that determine how openly and persistently the organization responds to the demands of digital and sustainable transformation.	González-Varona et al. (2021); Wang et al. (2022); Leso et al. (2023); Pfister and Lehmann (2023); Mojikon et al. (2025);
F6. Operational Processes and Practices	Degree to which internal workflows, production routines, and supply chain practices have been redesigned to integrate digital tools and embed sustainability principles throughout the value chain.	Ciliberto et al. (2021); Fontana et al. (2021); Kristoffersen et al. (2021); Ghadge et al. (2022); Kosasih et al. (2023)
F7. Performance Management and Measurement	Definition, monitoring, and evaluation of organizational progress across digital and sustainability dimensions through structured measurement frameworks and feedback mechanisms.	Barbosa et al. (2020); Stalmachova et al. (2022); Ramirez-Orellana et al. (2024)
F8. Financial Resources and Investment Capacity	Availability and strategic allocation of financial resources needed to fund the technology investments, skills development, and process redesign that twin transformation requires.	Ghobakhloo et al. (2022); OECD (2022)
F9. External Environment, Stakeholders, and Ecosystem	Constellation of external actors, institutional conditions, and market dynamics that shape the conditions under which SMEs pursue digital and sustainable transformation.	Matt et al. (2015); Vial (2019); European Parliament (2024); Gao (2024)

4. Application of the Methodology

The BWM was applied in three sequential steps following the procedure originally introduced by Rezaei (2015);

Step 1: Identification of best and worst criteria by each expert,

Step 2: Completion of Best-to-Others and Others-to-Worst comparison vectors,

Step 3: Calculation of optimal weights through the minimax optimization model (Rezaei 2015; Rezaei 2016).

All comparisons were performed using a 1–9 integer scale adapted from Saaty's fundamental scale (Saaty 1980), ranging from 1 (equal importance) to 9 (absolutely more important), with intermediate even values permitted to capture nuanced expert preferences.

The geometric mean of the three individual weight vectors was subsequently computed to yield the final consolidated factor weights, as recommended for multi-expert BWM applications (Mi et al. 2019).

4.1 Identification of Best and Worst Criteria

Each expert independently identified the criterion they considered most important (best) and least important (worst) from the full set of nine factors, drawing on their professional experience within the Turkish SME ecosystem. The selections are summarized in Table 2.

Table 2. Best and worst criteria by expert

Decision Maker	Best Criterion	Worst Criterion
Decision Maker 1	F3. Strategic Leadership and Management	F7. Performance Management and Measurement
Decision Maker 2	F4. Human Resources and Competencies	F9. External Environment, Stakeholders, and Ecosystem
Decision Maker 3	F8. Financial Resources and Investment Capacity	F7. Performance Management and Measurement

DM 1, whose background combines academic research with direct SME consultancy experience, identified strategic leadership as the most critical determinant of transformation outcomes. This judgment reflects the structural reality of Turkish SMEs, where the owner-manager typically concentrates strategic, operational, and change management responsibilities simultaneously, making leadership quality the primary accelerator or inhibitor of transformation. DM 2, drawing on eight years of project-based private sector experience across digital transformation and sustainability initiatives, identified human resources and competencies as the pivotal factor, consistent with the field observation that technology and strategy investments systematically stall in the absence of adequate workforce capabilities. DM 3, whose consultancy portfolio spans sustainability and digitalization projects across multiple firms and sectors, identified financial resources as the foundational constraint, grounded in the recurring observation that transformation initiatives fail not due to absence of intent but due to financial capacity exhaustion at critical implementation junctures. Performance management and measurement was independently selected as the least important factor by both DM 1 and DM 3, reflecting a shared assessment that formal measurement infrastructure, while conceptually valuable, remains institutionally immature across the Turkish SME population and is therefore a lower-order priority relative to the foundational enablers of transformation.

4.2 Best to Others Vectors

A Following the identification of best and worst criteria, each expert compared the best criterion against all remaining criteria using the 1–9 scale. The resulting Best-to-Others vectors are presented in Table 3.

Table 3. Best-to-Others (BO) comparison vectors

Decision Maker	F1	F2	F3	F4	F5	F6	F7	F8	F9
DM 1 (Best: F3)	3	4	1	3	4	5	7	6	6
DM 2 (Best: F4)	4	6	3	1	3	4	7	5	8
DM 3 (Best: F8)	4	6	3	4	5	6	9	1	7

4.3 Others to Worst Vectors

Each expert then compared all criteria against the worst criterion using the same scale. The resulting Others-to-Worst vectors are presented in Table 4.

Table 4. Others-to-Worst (OW) comparison vectors

Decision Maker	F1	F2	F3	F4	F5	F6	F7	F8	F9
DM 1 (Worst: F7)	7	5	8	7	6	5	1	4	3
DM 2 (Worst: F9)	6	4	7	8	6	5	2	4	1
DM 3 (Worst: F7)	7	4	7	6	5	4	1	9	3

4.4. Individual and Consolidated Factor Weights

The optimal weights derived for each decision-maker through the BWM minimax optimization model, together with the final consolidated weights obtained via geometric mean aggregation, are presented in Table 5.

Table 5. Individual BWM weights and consolidated geometric mean weights

	Weights								
	F1	F2	F3	F4	F5	F6	F7	F8	F9
Decision Maker 1	0.130	0.098	0.304	0.130	0.098	0.078	0.031	0.065	0.065
Decision Maker 2	0.098	0.065	0.131	0.314	0.131	0.098	0.056	0.078	0.029
Decision Maker 3	0.106	0.070	0.141	0.106	0.084	0.070	0.028	0.335	0.060
Geometric Mean	0.111	0.077	0.177	0.163	0.103	0.081	0.036	0.120	0.049

Examining the individual weight distributions, DM1 assigned the three highest weights to F3. Strategic Leadership and Management, F1. Digital Technology and Infrastructure, and F4. Human Resources and Competencies. For DM2, the three highest-weighted factors were F4. Human Resources and Competencies, F3. Strategic Leadership and Management, and F5. Organizational Culture and Change Readiness. DM3 assigned the highest weights to F8. Financial Resources and Investment Capacity, F3. Strategic Leadership and Management, and F4. Human Resources and Competencies.

Regarding the least important factors, DM1 assigned the three lowest weights to F7. Performance Management and Measurement, F8. Financial Resources and Investment Capacity, and F9. External Environment, Stakeholders, and Ecosystem. For DM2, the three lowest-weighted factors were F9. External Environment, Stakeholders, and Ecosystem, F2. Data Management and Analytical Capacity, and F7. Performance Management and Measurement. DM3 assigned the lowest weights to F7. Performance Management and Measurement, F9. External Environment, Stakeholders, and Ecosystem, and F2. Data Management and Analytical Capacity.

The consistency ratios (ξ^*) computed for each decision-maker's evaluation are reported in Table 6. All three values fall below the 0.10 threshold established in the BWM literature as the benchmark for high judgment reliability (Rezaei 2015; Rezaei 2016).

Table 6. BWM consistency ratios

Decision Maker	ξ^* Value	Assessment
DM 1	0.0875	High consistency
DM 2	0.0784	High consistency
DM 3	0.0872	High consistency

The proximity of the three ξ^* values to one another further indicates a comparable level of evaluation quality across all decision-makers, confirming that the derived individual weights and the consolidated geometric mean weights are reliable and suitable for interpretation in the subsequent section.

The final consolidated factor weights were obtained by computing the geometric mean of the three individual weight vectors, a aggregation approach recommended for multi-expert BWM applications to avoid the compensatory distortions associated with arithmetic averaging (Mi et al. 2019). The consolidated weight distribution, shown in Table 5., identifies F3. Strategic Leadership and Management, F4. Human Resources and Competencies, and F8. Financial Resources and Investment Capacity as the three highest-weighted critical success factors for twin transformation in Turkish SMEs. At the lower end of the distribution, F9. External Environment, Stakeholders, and Ecosystem, F7. Performance Management and Measurement, and F2. Data Management and Analytical Capacity received the three lowest consolidated weights, indicating that these factors are considered comparatively less critical by the expert panel within the current Turkish SME context.

5. Results and Discussion

The consolidated weight distribution emerging from the BWM analysis reveals a clearly stratified priority structure across the nine critical success factors. Three distinct layers are identifiable: a critical layer comprising F3 Strategic Leadership and Management (0.177), F4 Human Resources and Competencies (0.163), and F8 Financial Resources and Investment Capacity (0.120), which together account for 46.0% of total weight; a supporting layer comprising F1 Digital Technology and Infrastructure (0.111), F5 Organizational Culture and Change Readiness (0.103), and F6 Operational Processes and Practices (0.081), accounting for 29.5%; and a maturation layer comprising F2 Data Management and Analytical Capacity (0.077), F9 External Environment, Stakeholders, and Ecosystem (0.049), and F7 Performance Management and Measurement (0.036), accounting for the remaining 16.2%.

The dominance of the critical layer reflects the structural realities of the Turkish SME ecosystem. Strategic leadership ranks first, consistent with evidence that in SMEs where the owner-manager simultaneously concentrates strategic and operational responsibilities, leadership quality functions as either the primary transformation accelerator or its most consequential inhibitor (Rossato and Castellani 2020; Leipziger et al. 2025). Human resources and competencies ranks second, reflecting the compounding workforce demands created by the simultaneous pursuit of digital and green t transformations within severely constrained training budgets (OECD 2025). Financial resources ranks third, directly capturing the systematic underinvestment patterns driven by front-loaded capital requirements and macroeconomic pressures, exchange rate volatility, elevated inflation, and limited green finance penetration, that are particularly acute in the Turkish context (Ghobakhloo et al. 2022; Deniz 2025).

The supporting layer factors, digital infrastructure, organizational culture, and operational processes, are necessary for twin transformation to produce structural rather than superficial change, but their impact is contingent on the foundational conditions established by the critical layer. The maturation layer factors, by contrast, should not be interpreted as unimportant in absolute terms, but rather as dimensions whose institutionalization remains at an early stage across the Turkish SME population. The low weight assigned to external ecosystem factors notably diverges from European twin transformation literature, where institutional support mechanisms and industry cluster collaboration are frequently foregrounded as primary enablers (Abilakimova et al. 2025). This divergence likely reflects the comparatively less developed twin transformation support infrastructure in Turkey relative to EU member states operating within the European Green Deal policy architecture (Gao 2024; Deniz 2025).

6. Conclusion

This study identified and prioritized the critical success factors for twin transformation in Turkish SMEs by integrating a systematic literature review, Delphi-based expert consultation, and Best-Worst Method analysis across three domain experts. The resulting weight distribution reveals a stratified priority structure in which Strategic Leadership and Management, Human Resources and Competencies, and Financial Resources and Investment Capacity emerge as the most critical factors, collectively accounting for 46.0% of total weight. These findings suggest that Turkish SMEs and their supporting institutions should treat leadership capacity, workforce development, and financing access as foundational prerequisites for twin transformation rather than addressing them in parallel with lower-order organizational and technological investments.

The study contributes to the literature by extending twin transformation research to the Turkish SME context, applying a structured quantitative weighting methodology, and grounding the priority ordering in the convergent judgments of experts spanning academic, private sector, and consultancy backgrounds. Limitations include the size of the expert panel and the absence of sector or region specific differentiation, both of which future research should address through larger panels, comparative sectoral analyses, and cross-country designs that position Turkish SME transformation trajectories within the broader emerging economy context.

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