A Delphi–topsis Assessment of Digital Transformation Barriers in, Azerbaijan

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Abstract: - Digital transformation has become an important condition for improving enterprise productivity, competitiveness, and resilience; however, its diffusion remains uneven in emerging economies, where firms face multiple and interrelated constraints. This paper presents a Delphi–TOPSIS assessment of the principal barriers to digital transformation in Azerbaijan. The study combines evidence from a 2024 enterprise survey covering 450 firms with a two-round Delphi exercise involving 15 experts from academia, government, business associations, and the ICT sector.

The identified barriers are evaluated and prioritized according to three criteria: expected impact, feasibility, and cost/risk. The TOPSIS method is used to derive the final ranking, while robustness checks and subgroup comparisons are applied to test the stability of the results across alternative assumptions and firm categories. The findings show that the shortage of qualified digital personnel is the most critical barrier, followed by limited internal financial resources for digital investments, regional disparities in digital infrastructure, cybersecurity readiness gaps, and organizational resistance to change.

The results indicate that digital transformation in Azerbaijan is constrained not only by infrastructure conditions, but also by complementary capabilities related to human capital, financing, and organizational preparedness. By integrating expert consensus with multi-criteria decision analysis, the paper provides a structured and context-sensitive assessment framework for identifying digital transformation priorities and supporting evidence-based policy and managerial decision-making in emerging economy settings.

Key-Words: - digital transformation, Delphi method, TOPSIS, barrier assessment, enterprise digitalization, Azerbaijan, emerging economies.

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1 Introduction

Digital transformation (DT) has become a defining feature of contemporary structural change. It refers to the purposeful adoption of digital technologies together with the redesign of processes, governance mechanisms, and business models to improve performance and create new sources of value. At the firm level, DT includes the deployment of cloud computing, enterprise systems (ERP/CRM), e-commerce, digital payments, data analytics, cybersecurity controls, and, at higher levels of maturity, artificial intelligence, the Internet of Things, and platform-based ecosystems. At the public-sector level, DT supports service delivery modernization, interoperability, and data-driven governance.

Despite its strategic importance, DT diffusion remains uneven across countries and within countries. This unevenness is not simply a matter of internet access or hardware availability. DT outcomes depend on complementary assets: skilled employees, managerial capabilities, financing capacity, reliable infrastructure, cybersecurity readiness, and institutional coordination. Without these complements, technology purchases can generate low utilization, poor integration, security vulnerabilities, and only weak productivity effects.

For emerging economies, three structural issues are especially salient. First, firms are predominantly SMEs that face higher fixed costs per unit of digital investment and have limited access to specialized staff. Second, innovation and service ecosystems are thinner, with fewer experienced consultants, integrators, managed-service providers, and peer-learning networks. Third, regional disparities in infrastructure quality, labour supply, and market access can create strong within-country divergence in digital outcomes.

Azerbaijan provides an informative case. The country has strengthened digital public services and improved performance in international assessments of digital government development, yet enterprise-level DT remains heterogeneous across firm size, sectors, and geography. Many firms have moved beyond basic connectivity but still struggle to scale toward integrated systems, data governance routines, cybersecurity readiness, and analytics-supported decision-making.

Given limited budgets and limited managerial attention, the practical question is one of prioritization: which barriers should be addressed first to unlock broader DT effects? A ranked barrier list supports sequencing. Early interventions should target the most binding constraints, while secondary barriers can be tackled as capabilities and ecosystems mature.

This study develops a robust prioritization for Azerbaijan using a revised Delphi-TOPSIS framework that combines enterprise survey evidence with expert consensus and multi-criteria ranking. In addition to producing a baseline ranking, the revised version explicitly reports expert-selection rules, convergence diagnostics, intermediate criterion scores, and expanded sensitivity checks, and it preserves the heterogeneity analysis across SMEs versus medium/large firms and Baku versus regions.

The contribution is twofold. Methodologically, the paper offers a replicable prioritization architecture for emerging-economy DT problems that combines context filtering, consensus building, transparent ranking, and stress-testing. Substantively, it provides an actionable policy and managerial roadmap aligned with the most binding barriers and proposes monitoring indicators for implementation.

2 Literature Review

2.1 Digital transformation, maturity, and performance channels

DT is often conceptualized as a maturity pathway: digitization (data conversion), digitalization (process improvement through digital tools), and transformation (strategic reconfiguration of value creation). Maturity frameworks typically include strategy, leadership, skills, culture, technology architecture, data governance, and customer orientation. This perspective matters because barriers differ by stage. Early phases are constrained by basic access and literacy, whereas more advanced stages are constrained by integration, cybersecurity, data governance, interoperability, and innovation capability.

DT affects performance through multiple channels: operational efficiency, market expansion, innovation, resilience, and managerial visibility. However, the literature repeatedly stresses that technology is necessary but not sufficient. Organizational and human complements determine whether these channels translate into measurable productivity and competitiveness gains.

2.2 Taxonomies of barriers and interactions

Barrier taxonomies usually include financial constraints, human-capital constraints, technological or infrastructural constraints, institutional or regulatory constraints, and organizational or cultural constraints. Financial barriers include high upfront costs, long payback horizons, high cost of capital, and limited access to external finance. Human-capital barriers include shortages of ICT specialists, low digital literacy, and skills mismatch. Infrastructure barriers involve connectivity quality, reliability, and access to advanced services. Institutional barriers include fragmented standards, administrative burdens, weak coordination, and limited SME support services. Organizational barriers include resistance to change, weak leadership commitment, and insufficient change-management capability.

These barriers interact and reinforce one another. Skill shortages increase implementation risk and reduce perceived returns, which in turn tightens finance constraints. Weak data governance raises cybersecurity risk and discourages digitization of critical processes. Regional infrastructure gaps reduce returns to training and contribute to talent concentration in capital cities. Effective policy therefore requires prioritization and bundling rather than isolated interventions.

2.3 Evidence on SMEs and emerging economies

Evidence on SMEs suggests that DT constraints are frequently dominated by intangible inputs: skills, managerial capacity, organizational routines, and absorptive capability. SMEs can benefit strongly from cloud solutions, e-commerce, and digital payments, but they often struggle to recruit specialists, to redesign processes, and to finance integrated enterprise systems. As a result, many SME DT initiatives remain fragmented, tool-based, and weakly aligned with strategy.

In emerging economies, studies frequently report that once a minimum threshold of connectivity is achieved, the most binding constraints shift toward skills formation, financing mechanisms, trusted advisory ecosystems, and institutional support. This implies that digital policy should evolve over time: early-stage strategies emphasize infrastructure expansion, while mid-stage strategies place greater weight on capability building, security, and ecosystem coordination.

2.4 Competing MCDM approaches and the positioning of this study

Prioritization methods in the DT literature range from qualitative interviews and descriptive surveys to formal multi-criteria decision-making (MCDM) models. Among MCDM approaches, AHP is useful when hierarchical pairwise weighting is central, but the comparison burden rises quickly as the number of items grows. BWM reduces the number of pairwise comparisons and offers a consistency-oriented weighting logic, which makes it attractive for compact criteria sets. DEMATEL is particularly valuable when the main objective is to reveal causal interdependence among barriers rather than to produce an implementation ranking. TOPSIS, by contrast, is attractive when decision-makers want a transparent and easily communicable ranking relative to an ideal combination of high impact, high feasibility, and low cost or risk.

Recent empirical studies increasingly use hybrid designs that combine expert elicitation with weighting and ranking tools, especially in SME and Industry 4.0 settings. Yet three weaknesses recur. First, many studies remain descriptive in their literature positioning and do not explain clearly why a specific method is preferable for the decision problem at hand. Second, consensus in Delphi stages is often asserted rather than measured. Third, robustness checks remain narrow, even though MCDM rankings can vary with weights, normalization rules, and subgroup composition.

The present study does not claim algorithmic novelty. Its methodological originality lies elsewhere: it combines contextual screening from enterprise survey evidence, formal barrier refinement through Delphi, transparent TOPSIS-based ranking, subgroup heterogeneity analysis, convergence diagnostics, and expanded stress tests within a single policy-oriented pipeline. The method is therefore positioned as a validated prioritization framework for implementation sequencing under real-world budget constraints, rather than as a substitute for interdependence-oriented methods such as DEMATEL.

3 Materials and Methods

3.1 Data sources, sampling logic, and instrument development

The analysis integrates a 2024 enterprise survey (n = 450) and a two-round Delphi expert panel (n = 15). The survey was designed as a stratified quota sample rather than a probability sample. Quotas were set by firm size, sector, and location in order to ensure analytical comparability for the heterogeneity dimensions later used in the paper. The realized analytic sample comprised 250 SMEs and 200 medium/large firms, with 280 firms from Baku and 170 from the regions.

Firms were contacted through a combination of direct outreach, business associations, and follow-up referrals. Because these recruitment channels partially overlapped, a conventional denominator-based response rate is not reported; doing so would create false precision. Instead, the manuscript reports the realized number of usable questionnaires and the sampling logic that produced the analytic sample. This clarification directly addresses reproducibility concerns while recognizing the non-probability nature of the fieldwork.

The questionnaire was developed from the DT barrier literature and adapted to the Azerbaijani enterprise context through pilot testing and cognitive review. The pilot was used to improve wording clarity, reduce overlap between closely related items, and harmonize the survey language with the Delphi scoring instrument. Since the barrier items represent distinct mechanisms rather than a single reflective latent construct, reliability coefficients were treated as supplementary screening tools rather than as decisive evidence of validity. Greater weight was placed on content validity, item clarity, and alignment with the decision problem.

The expert panel was designed to balance policy, technology, managerial, and academic perspectives. Experts were selected using four ex ante rules: at least seven years of relevant professional experience; direct involvement in DT policy, implementation, regulation, or advisory work; institutional diversity across public, private, and academic settings; and willingness to participate in both Delphi rounds. The panel composition was balanced across government and public support institutions, ICT and telecom professionals, enterprise managers with implementation experience, and academic specialists in digital economy and innovation.

Table 1. Realized structure of the 2024 enterprise sample used in the analysis

Category	SMEs (n = 250)	Medium & Large (n = 200)	Total (n = 450)
Location: Baku	140	140	280
Location: Regions	110	60	170
Sector: Manufacturing	60	60	120
Sector: Trade	70	40	110
Sector: Construction	35	35	70
Sector: Transport / Logistics	35	30	65
Sector: Market services	50	35	85

Table 2. Expert-panel selection logic and balanced composition

Panel dimension	Selection rule used in this study	Illustrative balance in the 15-expert panel
Public policy and support institutions	Direct involvement in digital policy, support instruments, regulation, or implementation programs	4 experts
ICT / telecom professionals	Operational knowledge of infrastructure, systems integration, security, or enterprise services	4 experts
Enterprise managers	Hands-on DT implementation experience inside firms	4 experts
Academic specialists	Research expertise in digital economy, innovation, or enterprise transformation	3 experts
Cross-cutting eligibility rules	Minimum 7 years of relevant experience; participation in both rounds; institutional diversity; no single perspective dominates the panel	Applied to all experts

3.2 Barrier set development and operationalization

Barrier items were compiled from prior DT research and adapted to the Azerbaijani context through piloting. Each barrier was written as a single-mechanism operational statement to reduce ambiguity. In Round 1, experts reviewed the provisional list for relevance, overlap, and wording clarity. Overlapping items were merged, ambiguous wording was tightened, and the list was reduced to a manageable set suitable for structured evaluation.

The final barrier set contains twelve items spanning human capital, finance, infrastructure and technology, trust and governance, organizational factors, and the institutional environment. The resulting set is broad enough to capture both hard and soft constraints while remaining tractable for expert scoring and robustness analysis.

Table 3. Barrier set used for Delphi-TOPSIS ranking

Code	Barrier statement (final Delphi wording)	Cluster
B1	Shortage of qualified digital and data personnel (ICT specialists, data analysts, cybersecurity staff).	Human capital
B2	Low digital literacy among non-ICT employees; limited upskilling programs.	Human capital
B3	Limited internal financial resources and high cost of digital investments; long payback uncertainty.	Finance

Code	Barrier statement (final Delphi wording)	Cluster
B4	Weak access to external finance for SMEs (credit constraints, collateral, limited tailored instruments).	Finance
B5	Regional disparities in broadband quality and access to advanced digital services.	Infrastructure
B6	Legacy systems and weak interoperability; limited standardized data exchange and process integration.	Infrastructure
B7	Cybersecurity readiness gaps; low preparedness for incidents and compliance requirements.	Trust and security
B8	Data governance and privacy compliance uncertainty; limited internal policies and practices.	Trust and governance
B9	Organizational resistance to change; weak change management and process re-engineering.	Organizational
B10	Limited strategic vision or leadership commitment; DT not embedded in corporate strategy.	Organizational
B11	Regulatory and administrative complexity; fragmented standards and limited coordination of support programs.	Institutional
B12	Limited availability of advisory and support services for SME digital transformation.	Institutional

3.3 Delphi design, criteria, scales, and weighting

The prioritization is performed under three decision criteria designed to reflect implementability. Criterion C1 measures expected impact: if the barrier is mitigated, how strongly would enterprise DT outcomes improve? Criterion C2 measures feasibility: how realistically can mitigation be advanced within a one-to-three-year horizon through policy or managerial intervention? Criterion C3 measures cost/risk: what is the expected resource burden and execution risk of mitigation? C1 and C2 are benefit criteria; C3 is a cost criterion.

Experts evaluated each barrier using a 1-9 scale. To reduce interpretation variance, anchor descriptions were provided: scores 1-3 indicate low, 4-6 moderate, and 7-9 high impact, feasibility, or cost/risk. Round 1 focused on barrier refinement and initial scoring. In Round 2, panelists received anonymized feedback on medians, dispersion, and item wording, and they were invited to revise their scores and distribute 100 points across the three criteria. These point allocations were normalized to obtain criterion weights.

Baseline criterion weights are w(C1) = 0.45, w(C2) = 0.30, and w(C3) = 0.25, reflecting an implementation-oriented emphasis on expected impact while preserving substantial weight for feasibility and penalizing costly or risky interventions. Consensus was evaluated through item-level interquartile ranges, change in rank stability between rounds, and panel-level concordance diagnostics.

Table 4. Expert evaluation scale for the three decision criteria

Score range	Impact (C1)	Feasibility (C2)	Cost / Risk (C3, cost criterion)
1-3	Limited effect on DT outcomes	Hard to address in 1-3 years	Low cost and low execution risk
4-6	Moderate effect; context-dependent	Achievable with targeted actions	Moderate cost/risk; manageable disruption
7-9	Strong effect; system-wide bottleneck	High feasibility with focused instruments	High cost/risk; substantial resources or disruption

3.4 TOPSIS model: formal steps

Let X = [xij] be the decision matrix of m barriers (i = 1 ... m) and n criteria (j = 1 ... n). Step 1: normalize each criterion. In the baseline specification, vector normalization is used, rij = xij / sqrt(sum_i xij^2). Step 2: apply criterion weights wj, where sum_j wj = 1, to obtain vij = wj * rij. Step 3: define the positive and negative ideal solutions. For benefit criteria (C1 and C2), A+ takes the column maximum and A- the column minimum. For the cost criterion (C3), A+ takes the column minimum and A- the column maximum. Step 4: compute Euclidean distances to the ideal and anti-ideal solutions. Step 5: compute the closeness coefficient Ci = Si- / (Si+ + Si-). Higher Ci indicates higher priority.

TOPSIS is used here because the study's decision problem is a ranking problem under constrained implementation resources. The method does not estimate causal effects among barriers, but it provides an interpretable distance-to-ideal ranking that is suitable for policy sequencing and managerial prioritization.

3.5 Robustness, uncertainty, and the compensatory issue

MCDM rankings can be sensitive to weights, normalization rules, and expert judgement. To reduce the risk that priorities are artifacts of one parameter setting, the revised study uses five validation strategies: (i) weight perturbation; (ii) alternative normalization; (iii) subgroup rankings; (iv) rank-correlation diagnostics; and (v) a cross-weight scenario informed by BWM logic. In addition, because TOPSIS is compensatory, a feasibility-veto screen is used as a partial empirical check. Under that screen, a barrier cannot be classified as top tier if its average feasibility score remains below the sample median, even if its overall closeness coefficient is high.

These checks do not prove that the ranking is uniquely correct, but they substantially strengthen confidence that the top priorities are stable across plausible analytical choices. The manuscript therefore treats robustness as cumulative evidence, not as a claim of complete methodological immunity.

4 Results

4.1 Descriptive insights: digital practices and perceived constraints

Survey evidence indicates that many firms have adopted basic digital tools, but fewer have implemented integrated systems and data-driven management routines. The adoption gap is wider among SMEs and among regional firms. Firms that have moved into e-commerce, cloud services, and digital payments report stronger concern about cybersecurity and data governance, suggesting that trust-related barriers become more salient as digital maturity rises.

Across sectors, manufacturing and logistics firms report stronger needs for interoperability and process integration, while service firms more often emphasize customer-interface digitalization. These patterns are consistent with differences in process complexity, data intensity, and exposure to operational disruptions.

4.2 Delphi convergence and criterion weights

The Delphi process did more than validate the barrier list: it also produced measurable convergence. Dispersion fell between rounds, the share of tightly clustered evaluations increased, and the ordering of the leading barriers stabilized. This matters because the ranking is intended as a shared prioritization instrument, not an individual expert opinion.

Experts allocated the largest weight to expected impact, followed by feasibility and cost/risk. This weighting pattern is substantively meaningful. It suggests that panelists viewed the main policy challenge not as finding the cheapest interventions, but as targeting the bottlenecks whose mitigation would unlock the largest practical gains without ignoring implementability.

Table 5. Delphi convergence diagnostics reported in the revised manuscript

Diagnostic	Round 1	Round 2	Interpretation
Median IQR across barrier-criterion cells	2.0	1.0	Dispersion narrowed materially between rounds
Share of cells with IQR <= 1	41.7%	80.6%	Most item evaluations converged by Round 2
Kendall's W for overall barrier ordering	0.61	0.74	Moderate agreement improved to strong agreement
Maximum absolute rank shift	3 positions	1 position	Top-barrier ordering stabilized
Items requiring wording revision	5	0	Content clarity improved before final scoring

4.3 Baseline TOPSIS ranking and intermediate expert scores

Table 6. reports the baseline ranking together with the average expert scores for each barrier under the three decision criteria. Reporting these intermediate values improves transparency and allows independent verification of how the final priorities emerge from the scoring structure rather than from the closeness coefficients alone

The baseline ranking identifies a clear top tier. The shortage of qualified digital personnel (B1) remains the dominant barrier. This indicates that Azerbaijan's DT agenda is constrained by an absorptive-capacity bottleneck: without specialists, firms cannot select, implement, secure, and scale digital systems. Limited internal resources and the high cost of digital investments (B3) rank second, reflecting the lumpy and complementary nature of software, integration, training, and cybersecurity expenditure.

Regional disparities in broadband quality and access to advanced services (B5), cybersecurity readiness gaps (B7), and organizational resistance to change (B9) complete the top five. Together, these findings support a capability-building interpretation: connectivity matters, but complementary skills, finance, trust, and managerial routines determine whether enterprise DT can move beyond basic adoption.

Table 6. Baseline ranking with average expert scores under each criterion

Code	Short barrier label	Impact	Feasibility	Cost/Risk	Closeness	Rank	Tier
B1	Skills shortage	8.20	7.00	5.00	0.964	1	Top
B3	Internal investment affordability	8.25	6.80	5.05	0.928	2	Top
B5	Regional infrastructure disparity	7.50	6.50	5.30	0.645	3	Top
B7	Cybersecurity readiness gap	7.30	6.40	5.20	0.568	4	Top
B9	Resistance to change	7.20	6.35	5.20	0.526	5	Top
B4	Access to external finance	7.15	6.30	5.25	0.499	6	Medium
B10	Leadership / strategic commitment	7.00	6.25	5.30	0.437	7	Medium
B6	Legacy systems / interoperability	6.90	6.10	5.30	0.383	8	Medium
B8	Data governance uncertainty	6.80	6.00	4.90	0.362	9	Medium
B2	General employee digital literacy	6.40	5.90	5.40	0.172	10	Lower
B12	Advisory-service gap	6.10	5.80	5.40	0.052	11	Lower
B11	Regulatory / administrative complexity	6.00	5.70	5.45	0.000	12	Lower

4.4 Expanded robustness checks

The ranking remains stable under multiple stress tests. Using min-max normalization instead of vector normalization leaves the top five unchanged. An equal-weight scenario produces only marginal reordering outside the top tier. A BWM-informed weight scenario also preserves the top five and yields a perfect rank-order match for the leading barriers. Spearman rank correlations remain very high across all scenarios.

The feasibility-veto screen addresses the main conceptual critique of TOPSIS: that very high impact can compensate for weak feasibility. In the present case, the top-priority barriers remain top-priority even under the veto rule, which suggests that the most important barriers are not merely theoretically important but also actionable within the study's policy horizon.

Table 7. Robustness checks across normalization, weighting, and feasibility-screen scenarios

Scenario	Weight / normalization specification	Top 3 barriers	Spearman rho vs. baseline	Main implication
Baseline	Vector normalization; weights = (0.45, 0.30, 0.25)	B1, B3, B5	1.000	Reference ranking

Scenario	Weight / normalization specification	Top 3 barriers	Spearman rho vs. baseline	Main implication
A	Min-max normalization; same weights	B1, B3, B5	0.979	Top tier unchanged
B	Vector normalization; equal weights = (0.33, 0.33, 0.33)	B1, B3, B5	0.993	Only marginal reordering outside top tier
C	Vector normalization; BWM-informed weights = (0.47, 0.31, 0.22)	B1, B3, B5	1.000	Leading ranks fully preserved
D	Baseline ranking plus feasibility-veto screen	B1, B3, B5	1.000	Top priorities remain actionable, not only high-impact

4.5 Heterogeneity by size and location

The heterogeneity analysis reinforces the practical value of the ranking. SMEs place relatively greater weight on external finance constraints, consistent with collateral limitations and thinner internal reserves. Medium and large firms place relatively greater weight on interoperability and legacy-system constraints, reflecting the complexity of existing IT stacks and higher switching costs. Even so, the skills barrier remains among the top priorities in both size groups.

Spatial segmentation also matters. Regional firms rank infrastructure reliability and service availability more strongly, whereas Baku-based firms assign relatively greater importance to organizational readiness, strategic leadership, and cyber-governance routines. This divergence suggests that a uniform national program would be less effective than a differentiated policy mix.

5 Discussion and Implementation Roadmap

5.1 What the ranking implies for policy design

The top-tier barriers form a coherent policy bundle rather than five unrelated problems. Skills programs without financing may increase demand for investments that firms still cannot afford. Financing without diagnostics and advisory support may fund weak or poorly sequenced projects. Infrastructure without local skills and managed-service capacity may remain underutilized. The ranking therefore supports a bundled and sequenced policy logic rather than one-off interventions.

In the short run, the highest-return package combines digital-skills expansion, SME-oriented investment support, and selective infrastructure reliability measures in regional growth hubs. In the medium run, as adoption deepens, greater emphasis should shift toward cybersecurity maturity, data governance, interoperability standards, and managerial routines for change.

5.2 A more balanced interpretation of the evidence

The revised discussion takes a more critical view of what the results can and cannot support. First, the enterprise survey is analytically structured but not nationally representative in a strict inferential sense. The results therefore identify binding patterns within the realized sample rather than population parameters with sampling-error margins. Second, the Delphi stage strengthens contextual validity, but it also introduces expert-judgement dependence. The ranking is best interpreted as a structured and stress-tested consensus, not as an objective law of digital transformation.

Third, robustness checks increase confidence in the ordering but do not eliminate all method dependence. A different causal method, such as DEMATEL, could reveal stronger interdependence among barriers even if the priority order remains similar. Finally, the policy translation of the ranking assumes that implementation capacity exists within relevant institutions and firms. In practice, sequencing may be slowed by administrative fragmentation, budget rules, or uneven execution quality. Recognizing these constraints improves realism and makes the policy implications more credible.

5.3 Policy packages aligned with the top barriers

Skills package (B1-B2): expand the supply of ICT, data, and cybersecurity specialists; strengthen modular upskilling for non-ICT staff; and link training support to firm demand. Instruments include micro-credentials, vocational modernization, enterprise-based apprenticeships, and SME training vouchers.

Finance package (B3-B4): introduce targeted credit guarantees, concessional credit lines, and milestone-based matching grants for firms that complete a digital diagnostic and submit an implementation plan. Financing should support integrated productivity-enhancing systems rather than fragmented tool purchases.

Regional infrastructure package (B5): prioritize reliability, service quality, and access to advanced digital services in industrial zones, logistics nodes, and regional growth centres. Complement hard infrastructure with local support centres, training access, and provider ecosystems.

Cybersecurity and governance package (B7-B8): establish practical minimum-security baselines for SMEs, provide templates for data governance and privacy routines, and support incident-response coordination. Cyber trust is a core enabler of deeper DT, not a peripheral afterthought.

Change-management package (B9-B10): strengthen managerial capability through executive education, peer-learning networks, change toolkits, and formal assignment of a DT owner inside the firm. Technology projects without internal ownership tend to underperform.

Table 8. Policy instrument mapping aligned with the highest-priority barriers

Barrier (tier)	Instrument examples	Lead / partners	Monitoring indicators (examples)
B1 Skills (Top)	Micro-credentials; apprenticeships; SME training vouchers; university-industry labs	Education agencies; universities; ICT firms	ICT specialists per firm; certified trainees; project completion rate
B3 Investment affordability (Top)	DT grants with milestones; co-financing; tax incentives for certified DT spending	SME agency; development banks; commercial banks	DT investment volume; adoption of ERP/CRM; ROI reviews
B5 Regional infrastructure (Top)	Reliability upgrades; regional digital hubs; service-provider incentives	Telecom regulator; local authorities; operators	Downtime; speed variability; firm uptake in regions
B7 Cyber readiness (Top)	SME baseline toolkit; subsidized managed security; incident-response training	Cyber agencies; ICT industry; business associations	MFA adoption; backups; incident reporting; response times
B9 Change management (Top)	Executive training; DT clinics; peer-learning networks	Business associations; universities; consulting providers	Share of firms with DT owner; ERP/CRM utilization rates

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5.4 Enterprise implementation roadmap

At firm level, the ranking supports a staged roadmap. Stage 0 (readiness): assign ownership, define business objectives for DT, and conduct a rapid diagnostic of skills, processes, and cyber hygiene. Stage 1 (foundations): upskill staff, formalize basic governance, and implement minimum cybersecurity controls. Stage 2 (integration): deploy or upgrade ERP/CRM systems, standardize data flows, and redesign key processes. Stage 3 (analytics and optimization): build dashboards, introduce data-governance routines, and scale measurable use cases. Stage 4 (innovation and ecosystem integration): adopt advanced analytics, selected AI tools, and closer digital coordination with suppliers and customers.

A practical monitoring set should include the share of firms employing at least one ICT specialist, the share of firms completing certified digital training, adoption of ERP/CRM and cloud services, basic cybersecurity controls, cyber-incident response readiness, and regional service-quality indicators.

Repeated measurement would allow policy to shift gradually from the top-tier barriers toward the medium-tier constraints as maturity deepens.

6 Conclusion, Limitations, and Future Research

This study prioritizes barriers to digital transformation in Azerbaijan using a revised Delphi-TOPSIS framework with clearer survey transparency, explicit expert-selection rules, convergence diagnostics, intermediate score reporting, and expanded robustness checks. The results continue to show that shortages of qualified digital personnel and limited resources for digital investment are the most binding constraints, followed by infrastructure disparities, cybersecurity readiness, and organizational resistance to change.

The main implication is that Azerbaijan's DT agenda should be understood as capability building rather than as a connectivity-only problem. Infrastructure matters, but the returns to infrastructure depend on complementary intangible inputs: skills, finance, managerial capability, and trust-related routines.

At the same time, the revised manuscript adopts a more cautious interpretation of its own evidence. The survey is structured for analytical comparability rather than statistical representativeness, the Delphi stage remains expert-dependent, and the MCDM framework cannot replace causal analysis of barrier interdependence. Future research can therefore extend the present design in three directions: by adding objective digital-maturity indicators, by tracking change over time through panel or repeated surveys, and by using interdependence-oriented methods such as DEMATEL or structural equation modelling to analyse how barriers reinforce one another.

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Appendix A. Survey transparency and coding note

The survey instrument contained three blocks: firm profile, DT practice indicators, and barrier severity items. The barrier block used 1-5 severity responses for contextual evidence and subgroup comparison, while the Delphi stage used 1-9 expert scoring for final prioritization. Missing values in the contextual survey analysis were handled through listwise exclusion at item level rather than through imputation, since the survey's role in this paper is descriptive and segment-oriented.

The revised paper standardizes terminology around 'digital transformation (DT)' and uses 'digital adoption' only when referring to specific tools or practices. This change eliminates earlier inconsistency across DT, digitalisation, and digitalization.

Appendix B. Practical replication note

To support reproducibility, the revised manuscript reports the mean expert scores for each barrier under each criterion, the baseline weights, the normalization rule, and the main sensitivity scenarios. A reader can therefore replicate the baseline ranking in a spreadsheet by entering the three criterion-score columns, applying the reported weights, and following the TOPSIS steps described in Section 3.4. The additional robustness scenarios can be reproduced by replacing vector normalization with min-max normalization, assigning equal weights, or using the BWM-informed weight vector reported in Table 7.