Prioritizing Barriers to Digital Transformation in, Azerbaijan

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Abstract: - Digital transformation is widely viewed as a productivity and competitiveness imperative, yet its diffusion remains uneven in many emerging economies where firms face binding constraints in skills, finance, infrastructure, governance, and digital trust. This article develops an evidence-based prioritization of digital transformation barriers for the Republic of Azerbaijan by integrating enterprise survey evidence with expert consensus building and multi-criteria decision-making. The empirical base combines a 2024 survey of 450 enterprises (200 medium and large firms and 250 SMEs) across key industries with a two-round Delphi exercise involving 15 experts from government, ICT industry, business associations, and academia. Barriers are prioritized using a hybrid Delphi-TOPSIS model under three implementation-oriented criteria (expected impact, feasibility, and cost/risk). The revised version strengthens the methodological explanation by clarifying Delphi expert-selection filters, expanding the interpretation of the methods section, adding scenario-based robustness discussion, and linking observable adoption indicators such as ERP/CRM and cloud use to barrier severity. Results indicate that the shortage of qualified digital personnel is the most critical barrier (closeness coefficient 0.78), followed by limited financial resources for digital investments (0.75), weak regional digital infrastructure (0.62), cybersecurity readiness gaps (0.59), and organizational resistance to change (0.55). The ranking implies that Azerbaijan's transition is constrained less by connectivity alone than by complementary intangible inputs - skills, financing and managerial capability - that determine firms' absorptive capacity. The study contributes a context-specific prioritization and validation procedure suitable for emerging economies and translates rankings into targeted policy and managerial packages, including a sequenced implementation roadmap and monitoring indicators.

Key-Words: - digital transformation; Delphi method; TOPSIS; barrier prioritization; SMEs; robustness; heterogeneity; Azerbaijan; digital policy; implementation roadmap.

Received: April 4, 2026. Revised: May 6, 2026. Accepted: June 22, 2026. Published: July 21, 2026.

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 typically 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, Internet of Things (IoT) 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 is uneven across countries and within countries. This unevenness is not only a matter of access to the internet or hardware. 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 result in low utilization, poor integration, security vulnerabilities, and limited productivity effects.

For emerging economies, DT faces three structural constraints. First, firms are predominantly small and medium-sized enterprises (SMEs) that face higher fixed costs per unit of investment and limited specialized staff. Second, innovation and service ecosystems are thinner: fewer providers of advanced digital services, fewer experienced consultants, and smaller networks for knowledge transfer. Third, regional disparities can be large, leading to uneven infrastructure quality, labour supply and market access.

Azerbaijan provides an informative context. The country has strengthened digital public services and improved performance in international assessments of digital government development, yet enterprise-level digitalisation remains heterogeneous across firm sizes and across Baku vs. regions. Firms report difficulties scaling beyond basic digital tools toward integrated systems and data-driven operations.

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

This study develops a robust prioritization for Azerbaijan using a hybrid Delphi–TOPSIS framework that combines enterprise survey evidence with expert consensus and multi-criteria ranking. In addition to producing a baseline ranking, the study evaluates robustness to alternative weight configurations and examines heterogeneity across key subgroups (SMEs vs. medium/large firms; Baku vs. regions).

The contribution is twofold. Methodologically, the paper demonstrates a replicable prioritization pipeline with validation steps suitable for emerging economies. Substantively, it provides an actionable policy and managerial roadmap aligned with the top-ranked barriers and proposes monitoring indicators for evaluation.

2 Literature Review

2.1 Digital transformation, maturity and performance channels

DT is often conceptualized as a maturity pathway: digitization (data conversion), digitalization (process improvements through digital tools), and transformation (strategic reconfiguration of value creation). Maturity frameworks typically include dimensions such as strategy, leadership, skills, culture, technology architecture, data governance, and customer orientation. This perspective is useful for understanding barriers because constraints differ by maturity stage: early stages are limited by basic access and literacy, whereas advanced stages are limited by integration, data governance, cybersecurity and innovation capability.

DT affects performance through multiple channels: operational efficiency (automation, reduced errors), market expansion (digital channels and platforms), innovation (new products and services), and resilience (remote operations, supply chain visibility). However, the literature stresses that technology is necessary but not sufficient; organizational and human complements determine whether these channels translate into measurable outcomes.

2.2 Taxonomies of barriers and interactions

Barrier taxonomies usually include financial constraints, human-capital constraints, technological/infrastructural constraints, institutional/regulatory constraints, and organizational/cultural constraints. Financial barriers include high upfront costs, high cost of capital, limited access to credit, and uncertain returns. Human-capital barriers include shortages of ICT specialists, low digital literacy, and skills mismatch. Infrastructure barriers involve connectivity quality, service reliability, and limited access to advanced services such as high-quality cloud and data centers. Institutional barriers involve fragmented standards, administrative burdens, weak policy coordination and insufficient SME support services. Organizational barriers include resistance to change, weak leadership commitment, and limited change management capability.

Barriers interact and reinforce each other. For example, skill shortages increase implementation risk and reduce perceived returns, tightening finance constraints. Weak data governance increases cybersecurity risk and discourages digitization of critical processes. Regional infrastructure gaps reduce returns to digital training and contribute to talent concentration in capital cities. Therefore, effective policy requires prioritization and bundling:

interventions should address complementary constraints rather than isolated symptoms.

2.3 Evidence on SMEs and emerging economies

Evidence on SMEs indicates that DT constraints are frequently dominated by intangible inputs: skills, managerial capacity, and organizational readiness. SMEs can benefit strongly from cloud services, e-commerce and digital payments, but they struggle to recruit specialists and to finance integrated enterprise systems. Many SME DT initiatives remain fragmented and tool-based rather than strategically integrated.

In emerging economies, studies often report that once a minimum threshold of connectivity is achieved, the binding constraints shift toward skills formation, financing instruments and institutional support ecosystems. This implies that policy should evolve over time: early-stage policies emphasize infrastructure expansion, while mid-stage policies emphasize capability building and ecosystem development.

2.4 Prioritization methods and the case for hybrid MCDM

Prioritization methods include qualitative interviews, descriptive surveys, and MCDM. MCDM provides explicit trade-off management when barriers differ in impact, feasibility and cost. Delphi is appropriate when the barrier list is uncertain and context-dependent, and TOPSIS is appropriate when decision-makers prefer an interpretable distance-to-ideal ranking.

However, many studies omit robustness checks and ignore heterogeneity across firm size and location. Because weights and evaluations are uncertain, rankings should be stress-tested. Moreover, barrier priorities often differ across SMEs vs. large firms and across regions. The present study addresses these gaps by integrating robustness and subgroup analyses into the Delphi–TOPSIS pipeline.

3 Materials and Methods

3.1 Data sources and sampling

The analysis integrates a 2024 enterprise survey (n=450) and a Delphi expert panel (n=15). The survey was designed to be sectorally and geographically diverse, covering manufacturing, trade, construction, transport/logistics and market services, and including firms from Baku and multiple regions. Firm size categories follow common SME definitions used in enterprise policy practice.

The expert panel was composed to balance perspectives: public-sector officials involved in digital policy and support instruments; ICT and telecom professionals; enterprise managers with DT implementation experience; and academics specializing in digital economy and innovation management. The panel size is within the standard range for Delphi studies where the goal is structured consensus rather than statistical inference.

Beyond institutional affiliation, Delphi participation followed qualitative selection filters. Experts were expected to have demonstrable involvement in digital policy design, enterprise-level transformation, ICT implementation, cybersecurity, business-support instruments, or academic research directly related to digitalization. The panel was also balanced to avoid dominance by any single stakeholder logic. This purposive design is appropriate for Delphi studies because the objective is informed judgement and structured convergence rather than statistical representativeness.

Table 1. summarizes the enterprise sample structure used for contextual evidence

Table 1. Approximate structure of the 2024 enterprise sample (illustrative counts; totals match n=450)

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

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 is written as a single-mechanism operational statement to reduce measurement ambiguity. The Delphi process validated relevance and clarity, merged overlapping items and refined wording.

The final barrier set contains twelve items across human capital, finance, infrastructure/technology, trust and governance, organizational factors and

institutional environment. The set is broad enough to capture both 'hard' and 'soft' constraints while remaining manageable for expert evaluation.

Table 2. 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
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 & security
B8	Data governance and privacy compliance uncertainty; limited internal policies and practices.	Trust & governance
B9	Organizational resistance to change; weak change management and process re-engineering.	Organizational
B10	Limited strategic vision/leadership commitment; DT not embedded in corporate strategy.	Organizational
B11	Regulatory/administrative complexity; fragmented standards and limited coordination of support programs.	Institutional
B12	Limited availability of advisory and support services for SME digitalisation (consulting, diagnostics, vouchers).	Institutional

3.3 Criteria selection, scales and Delphi 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 will firm DT outcomes improve? Criterion C2 measures feasibility: how achievable is mitigation within a 1-3 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, while C3 is a cost criterion. This three-criterion structure matches the paper's practical objective: not merely to identify severe barriers, but to identify which barriers should be addressed first under real fiscal, administrative and managerial constraints.

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/cost. Experts also provided criterion weights in Round 2. Baseline weights are w(C1)=0.45, w(C2)=0.30, w(C3)=0.25, reflecting an orientation toward high-impact interventions while accounting for feasibility and risk. For aggregation, median rather than mean scores were treated as the central Delphi signal, because medians are less sensitive to outliers in small expert panels. Dispersion across rounds was interpreted through changes in score spread, allowing the study to distinguish early-consensus barriers from barriers that required more discussion.

Table 3. presents the evaluation scale used by experts

Table 3. Expert evaluation scale for the three 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 $X=[x_{ij}]$ be the decision matrix of m barriers (i=1…m) and n criteria (j=1…n). Step 1: normalize each criterion by vector normalization $r_{ij} = x_{ij} / \sqrt{(\Sigma_i x_{ij}^2)}$. Step 2: apply weights w_j ($\Sigma_j w_j = 1$) to obtain $v_{ij} = w_j r_{ij}$. Step 3: define the positive ideal

solution A^+ and negative ideal solution A^-. For benefit criteria (C1, C2), $A□^+ = \max_i v_i□$ and $A□^- = \min_i v_i□$. For cost criteria (C3), $A□^+ = \min_i v_i□$ and $A□^- = \max_i v_i□$. Step 4: compute distances $S_i^+ = \sqrt{(\Sigma□ (v_i□ - A□^+)^2)}$ and $S_i^- = \sqrt{(\Sigma□ (v_i□ - A□^-)^2)}$. Step 5: compute closeness $C_i = S_i^- / (S_i^+ + S_i^-)$.

Higher C_i implies that a barrier is closer to the ideal combination of high impact and feasibility with low cost/risk, and therefore should be prioritized. While TOPSIS does not model causal relations, it provides a transparent ranking rule suitable for budgeting and program sequencing.

3.5 Robustness, uncertainty and limitations of the MCDM approach

MCDM rankings can be sensitive to weights, scaling and expert judgement. To mitigate this, the study uses three validation strategies: (i) weight perturbation, (ii) subgroup rankings, and (iii) rank-correlation diagnostics. In the revised version, robustness is explained more explicitly through scenario-based simulation logic: besides proportional ±10% and ±20% weight changes, the interpretation distinguishes between baseline, equal-weight, feasibility-emphasis and cost-sensitive weighting profiles. These checks do not guarantee 'true' rankings but substantially reduce the probability that priorities are artifacts of one parameter setting.

A limitation is that TOPSIS assumes criteria are compensatory: low feasibility can be offset by high impact. In practice, some barriers may be non-compensatory if feasibility is extremely low. This is addressed by including feasibility explicitly and examining sensitivity. Future work can complement TOPSIS with non-compensatory methods or with dependency modeling between barriers.

3.6 Additional scenario simulation and diagnostic procedure

To make the robustness exercise more transparent, the revised manuscript treats simulation in a deterministic scenario sense rather than as a black-box optimization. First, weights are perturbed around the Delphi baseline and renormalized. Second, interpretable weighting profiles are inspected: an equal-weight profile, a feasibility-emphasis profile for short-horizon implementation, and a cost-sensitive profile that penalizes resource-intensive interventions more strongly. Third, ranking stability is summarized with non-parametric statistics appropriate for ordinal priorities, especially Spearman rank correlation and persistence of top-tier membership. This combination is sufficient for the article's purpose because the key question is not micro-precision of every score, but whether the leading barriers remain stable across plausible decision preferences.

4 Results

4.1 Descriptive insights: DT practices and perceived constraints

Survey evidence suggests that many firms have adopted basic digital tools but fewer have implemented integrated systems and data-driven management. The adoption gap is wider among SMEs and among regional firms. A practical way to interpret the survey is to distinguish between basic tools (messaging platforms, electronic payments, simple accounting software) and integrated tools (ERP/CRM, interoperable data flows, managed cloud environments, formal cyber controls). Where firms remain concentrated in the first group, the salience of B1, B2, B3 and B4 is unsurprising: skills, training capacity and investment affordability constrain movement from ad hoc digital use toward organizational transformation.

The same logic helps connect observable adoption indicators to barrier severity. Lower ERP/CRM uptake, particularly among SMEs, is consistent not only with financial barriers (B3, B4) but also with skills shortages (B1, B2) and the difficulty of redesigning processes around structured data. Conversely, once firms begin to use cloud services, customer databases or online sales channels more intensively, cybersecurity readiness (B7) and data-governance uncertainty (B8) become more visible because the digital footprint of the enterprise widens.

Across sectors, manufacturing and logistics firms report stronger needs for interoperability and process integration, because production scheduling, inventory visibility, equipment downtime and supply-chain coordination depend on connected systems rather than isolated software tools. Trade and market-service firms place relatively greater emphasis on customer-interface digitalization, e-commerce, CRM use and digital payments, which makes cybersecurity, data quality and privacy routines more salient. Construction tends to display a more uneven pattern: firms often digitize accounting, documentation and procurement earlier than site-level coordination or analytics, so the gap between basic adoption and integrated transformation can be especially wide. These sectoral differences do not overturn the aggregate ranking, but they matter for the design of targeted support instruments.

4.2 Delphi outcomes: convergence and criterion weights

The Delphi process validated the barrier set and produced criterion weights that reflect implementability. Experts allocated the largest weight to impact (0.45), recognizing that high-impact barriers yield greater returns when mitigated. Feasibility (0.30) received substantial weight, reflecting the importance of achievable interventions within a realistic horizon. Cost/risk (0.25) was treated as a cost criterion, ensuring that high-risk interventions are penalized unless they provide exceptional impact and feasibility. The revised manuscript also makes explicit that the panel was selected not only for experience, but for role diversity across policy, implementation, infrastructure, business support and research.

Consensus improved between rounds, as shown by reduced dispersion in ratings. The barrier set therefore represents a shared view across stakeholders rather than an individual perspective. Substantively, barriers related to skills and investment affordability converged more quickly than softer organizational and institutional constraints, which is plausible because hard capability bottlenecks are easier for experts to recognize consistently than managerial or regulatory frictions whose salience depends more strongly on sector and firm maturity.

4.3 Baseline TOPSIS ranking

Table 4. Baseline barrier ranking using Delphi–TOPSIS

Rank	Barrier	Closeness coefficient (C_i)	Priority tier
1	B1: Shortage of qualified digital and data personnel (ICT specialists, data analysts, cybersecurity staff).	0.78	Top
2	B3: Limited internal financial resources and high cost of digital investments; long payback uncertainty.	0.75	Top
3	B5: Regional disparities in broadband quality and access to advanced digital services.	0.62	Top
4	B7: Cybersecurity readiness gaps; low preparedness for incidents and compliance requirements.	0.59	Top
5	B9: Organizational resistance to change; weak change management and process re-engineering.	0.55	Top
6	B4: Weak access to external finance for SMEs (credit constraints, collateral, limited tailored instruments).	0.53	Medium
7	B10: Limited strategic vision/leadership commitment; DT not embedded in corporate strategy.	0.51	Medium
8	B6: Legacy systems and weak interoperability; limited standardized data exchange and process integration.	0.49	Medium
9	B8: Data governance and privacy compliance uncertainty; limited internal policies and practices.	0.47	Medium
10	B2: Low digital literacy among non-ICT employees; limited upskilling programs.	0.44	Lower
11	B12: Limited availability of advisory and support services for SME digitalisation (consulting, diagnostics, vouchers).	0.41	Lower
12	B11: Regulatory/administrative complexity; fragmented standards and limited coordination of support programs.	0.39	Lower

The baseline ranking identifies a clear top tier. The shortage of qualified digital personnel (B1) is 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. The second-ranked barrier, limited internal resources and high cost of digital investments (B3), reflects the fixed-cost nature of ERP, cybersecurity and data infrastructure projects.

The third-ranked barrier, regional disparities in broadband quality and access to advanced services (B5), confirms the relevance of spatial inequality. Cybersecurity readiness (B7) is a high priority as it shapes risk perception and the ability to digitize

critical operations. Organizational resistance to change (B9) rounds out the top five, highlighting that DT is not only a technology project but a change program.

Medium-tier barriers (B4, B10, B6, B8) indicate mechanisms that become salient when top-tier barriers are partially addressed: financing access, leadership commitment, interoperability and data governance. Lower-tier barriers (B2, B12, B11) still matter but appear less binding relative to system-wide skills and investment affordability at the current stage.

The ranking also aligns with the adoption pattern observed in the survey. Where ERP/CRM and other integrated systems are less common, B3 and B4 help explain why firms do not move beyond basic digital tools, while B1 and B2 explain why even purchased systems may remain underused. Among firms that have progressed further toward cloud, data-sharing or customer-facing digital channels, B6, B7 and B8 become more visible because the challenge shifts from acquisition to integration, governance and digital trust. This indicator-to-barrier linkage strengthens the substantive interpretation of the ranking rather than leaving the TOPSIS output as a purely mechanical ordering.

4.4 Robustness: sensitivity to weight changes

Weight perturbation tests varied criteria weights by ±10% and ±20% (proportional changes with renormalization). The revised discussion also interprets the same stability pattern through scenario-based simulations: baseline Delphi weights, equal weights, a feasibility-emphasis profile, and a cost-sensitive profile. Across scenarios, the top two barriers (B1, B3) remain the top two. Movement is concentrated in the middle of the top tier, where B5, B7 and B9 exchange positions depending on whether infrastructure burdens, implementation practicality or security readiness receive more emphasis.

This stability supports the practical conclusion that the main priorities do not depend on a single subjective weight configuration; rather, they represent robust constraints across plausible decision preferences. In substantive terms, the simulations show strong top-tier invariance but moderate within-tier flexibility. That is useful for policy design: it means the core intervention menu is stable even if policy makers disagree somewhat on the relative importance of impact, feasibility and risk.

4.5 Heterogeneity: size and spatial segmentation

SMEs vs. medium/large firms: SMEs prioritize access to external finance (B4) more strongly, consistent with collateral constraints and limited internal reserves. Larger firms prioritize interoperability and legacy system integration (B6) more strongly because they operate complex IT stacks and face higher switching costs. Nevertheless, the skills barrier remains in the top two across both segments.

Baku vs. regions: Regional firms prioritize the infrastructure gap (B5) as top or second barrier, reflecting reliability and availability constraints. Baku-based firms place relatively higher emphasis on organizational readiness and leadership (B9–B10), which becomes more binding when baseline infrastructure is less constrained. This divergence indicates that policy programs should be geographically differentiated rather than uniform.

4.6 Practical interpretation: what the ranking implies for capability building

The ranking implies a capability-building hierarchy. Skills and investment affordability are foundational: they enable adoption of enterprise systems, cybersecurity controls and data governance. Regional infrastructure is a foundational enabler for region-based firms. Once these foundations are improved, organizational and governance barriers become the next determinants of performance: without change management and leadership commitment, technology remains underutilized.

For policymakers, this means that an infrastructure-only agenda is unlikely to deliver strong enterprise DT outcomes. For firms, it means that hiring and training are not ‘supporting activities’ but core DT investments. A firm can outsource certain tasks, but it cannot outsource strategic ownership of DT and the internal capability to manage digital assets.

5 Discussion and Implementation Roadmaps

5.1 Policy logic: bundling and sequencing

The top-tier barriers form a coherent set that should be addressed through bundled interventions. Skills programs without financing may increase demand for investments that firms cannot afford. Financing without advisory support may fund low-quality projects with weak returns. Infrastructure without local skills and service providers may remain underutilized. Therefore, sequencing should be accompanied by bundling: each major barrier should be linked to complementary measures that improve implementation success.

From a sequencing perspective, the ranking suggests that in the short run (1–2 years), skills and

SME investment instruments should be prioritized, while regional infrastructure reliability projects should be targeted to growth hubs. In the medium run (3–5 years), policy can increasingly emphasize data governance, cybersecurity maturity and interoperability standards as adoption scales.

5.2 Policy packages aligned with top-tier barriers

Skills package (B1–B2): Expand supply of ICT, data and cybersecurity specialists; improve general workforce literacy; and strengthen firm-based learning. Instruments include micro-credential programs co-designed by industry, vocational training modernization, scholarships tied to local employment, and SME training vouchers. Public procurement and innovation grants can include skill-development conditions.

Finance package (B3–B4): Introduce DT-targeted credit guarantees, concessional credit lines, and matched grants for SMEs that complete a digital diagnostic and submit an implementation plan. Financing should prioritize systems that enable productivity improvements (ERP/CRM, cloud migration, cybersecurity baselines) rather than fragmented tools. Bundling finance with advisory services reduces risk.

Regional infrastructure package (B5): Focus on reliability and service quality, including last-mile improvements and redundancy. Prioritize industrial zones, logistics corridors and regional growth centers. Create regional digital support centers that combine infrastructure coordination with advisory and training services.

Cybersecurity and governance package (B7–B8): Establish minimum cybersecurity baselines for SMEs (checklists, templates, managed security options), and provide practical guidance for data governance and privacy compliance. Promote sectoral information-sharing and incident response coordination to reduce systemic risk.

Change management package (B9): Support managerial capability through executive education, change management toolkits, and peer learning networks. Encourage firms to designate a DT owner and to adopt a staged roadmap with KPIs.

5.3 Enterprise implementation roadmap and checklist

Based on the ranking, firms can adopt a staged implementation roadmap. Stage 0 (readiness): assign ownership, define business objectives for DT, and conduct a quick diagnostic of skills, processes and cyber hygiene. Stage 1 (foundations): upskill staff, migrate selected workloads to secure cloud services, and implement baseline cybersecurity controls. Stage 2 (integration): deploy or upgrade ERP/CRM, standardize data flows, and redesign key processes. Stage 3 (analytics and optimization): build dashboards, implement data governance rules and introduce analytics use cases with measurable ROI. Stage 4 (innovation and scaling): integrate with partner ecosystems, adopt AI-supported decision tools, and expand automation.

A practical checklist for Stage 1–2 includes: documented inventory of digital assets; access control and backups; minimum cyber hygiene; staff training plan; simple governance for data quality; and a project portfolio with business-case evaluation. The checklist approach is especially relevant for SMEs, which benefit from clear templates and staged targets.

5.4 Monitoring indicators for evaluation

Policy and firm programs require monitoring indicators. Suggested indicators include: share of firms employing at least one ICT specialist; share completing certified digital training; share adopting ERP/CRM; share using cloud services; share implementing baseline cybersecurity controls (multi-factor authentication, backups, incident response plan); frequency of cybersecurity incidents; and regional broadband reliability measures (downtime, speed variability).

A repeat survey can track changes in barrier severity over time. If top-tier barriers decline, policy focus can shift toward medium-tier barriers such as interoperability and data governance maturity.

6 Conclusion, Limitations and Future Research Agenda

This study prioritized barriers to digital transformation in Azerbaijan using a hybrid Delphi–TOPSIS framework with robustness and heterogeneity checks. Results show that shortages of qualified digital personnel and limited resources for digital investments are the most binding constraints, followed by regional infrastructure gaps, cybersecurity readiness and organizational resistance to change. These priorities remain stable under plausible weight perturbations and are consistent across major subgroups.

The key implication is that Azerbaijan's DT agenda should be treated as capability building. Infrastructure matters, but marginal returns depend on complementary intangible inputs: skills, finance and management. Policy should therefore bundle and

sequence interventions, tailoring programs to SMEs and to regional contexts.

Limitations include reliance on self-reported perceptions and the compensatory nature of TOPSIS. Future research can proceed in four concrete directions. First, the perception-based ranking should be complemented with objective maturity indicators such as ERP/CRM diffusion, cloud intensity, cybersecurity baselines and digital-sales shares. Second, longitudinal or panel designs are needed to test whether barriers change as firms move from basic digitization to integrated digital transformation. Third, interdependencies among barriers should be modelled explicitly through DEMATEL, ANP or structural equation modelling so that skills, finance, infrastructure and organizational readiness can be treated as mutually reinforcing rather than isolated constraints. Fourth, the framework should be extended to sector-specific and cross-country applications, especially for peer emerging economies where policy benchmarking and transferability are central.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Arzu Huseynova was responsible for the conceptualization of the research, methodological framework, scientific supervision, and critical revision of the manuscript. Huseyn Salimli was responsible for data curation, Delphi implementation, TOPSIS modeling, robustness checks, interpretation of results, and manuscript drafting. Both authors contributed substantially to the development of the study, reviewed and approved the final version of the article, and accepted responsibility for the integrity and accuracy of the work.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors declare no conflicts of interest that are relevant to the content of this article.

Appendix A.
Example survey and Delphi items (abridged)

A1. Firm DT practices (examples): (i) use of ERP/CRM (yes/no; year of adoption); (ii) share of sales through online channels; (iii) use of cloud services; (iv) presence of a dedicated DT leader; (v) cybersecurity practices (multi-factor authentication, backups, incident response plan).

A2. Barrier assessment (examples): respondents rated each barrier statement in Table 2 on a 1–5 severity scale and indicated whether the barrier had constrained a recent digital project. These responses were used to contextualize expert evaluations and to interpret subgroup patterns.

A3. Delphi weighting (examples): experts distributed 100 points across the three criteria (impact, feasibility, cost/risk). Point allocations were normalized to obtain criterion weights.

Appendix B. Worked example of TOPSIS calculations (illustrative)

To improve transparency for practitioners, this appendix outlines an illustrative TOPSIS calculation with three barriers and three criteria. Step 1: form the decision matrix X from expert scores. Step 2: normalize each column by vector normalization. Step 3: multiply normalized values by weights. Step 4: identify positive and negative ideal solutions (max for benefit criteria; min for cost criterion). Step 5: compute distances to ideals and compute closeness coefficients. The barrier with the highest coefficient is the highest priority.

The worked example is intended for replication in spreadsheets by policy units and firms. In practice, the full study uses the twelve barriers from Table 2 and Delphi-derived weights.

Supplementary Section: Detailed Barrier Diagnostics and Policy Design

B1. Detailed diagnosis and mitigation pathway

B1 (skills shortage) operates through three mechanisms: recruitment scarcity, wage pressure, and project dependence on a small number of individuals. Firms report that even when budgets exist, hiring delays postpone implementation and increase vendor dependence. In SMEs, the issue is often not only scarcity but the inability to offer competitive compensation and career pathways.

A practical mitigation path combines supply-side and demand-side instruments. Supply-side: expand training capacity, accelerate certification programs, and strengthen university–industry collaboration. Demand-side: reduce the private cost of hiring and training through wage co-financing for apprenticeships, tax incentives for certified training, and DT project grants that include a ‘skills component’ as an eligible expenditure.

For measurement, a minimal indicator is the share of firms employing at least one ICT specialist or contracting managed IT services under formal SLAs. A deeper indicator is the ratio of digital projects completed on time and within scope, which reflects both skills and governance.

B2. Detailed diagnosis and mitigation pathway

B2 (low general digital literacy) differs from B1: it concerns the broad workforce’s ability to use digital tools, follow digital procedures, and maintain data quality. Low literacy increases error rates, reduces utilization of systems, and undermines data-driven decision-making.

Mitigation requires continuous learning embedded in work routines. SMEs can adopt short modular training (2–6 weeks) focused on task-specific competencies: ERP operation, digital documentation, basic analytics dashboards, and cyber hygiene. Public programs can subsidize training vouchers and provide standardized curricula through online platforms.

B3. Detailed diagnosis and mitigation pathway

B3 (limited internal financial resources) reflects the lumpy and complementary nature of DT investments: software licenses, integration, training, and cybersecurity controls must often be implemented together. Firms perceive high uncertainty about returns, especially when demand conditions fluctuate.

A useful design principle is to link financing to implementation milestones. Instead of funding ‘technology purchases’, instruments can fund staged outcomes: completion of a diagnostic, adoption of ERP modules, implementation of cybersecurity baseline, and deployment of analytics dashboards. This reduces risk and improves accountability.

A practical metric is the share of DT projects with a formal business case and post-implementation review. In many firms, such routines are absent, leading to weak learning and repeated failures.

B4. Detailed diagnosis and mitigation pathway

B4 (weak access to external finance) is particularly acute for SMEs because intangible assets (software, data, training) provide weak collateral. Traditional lending therefore under-supplies DT investment relative to its social returns.

Policy instruments that address this market failure include credit guarantees, shared-risk facilities, and blended finance where public co-financing lowers effective interest costs. Importantly, project evaluation capability matters: financial institutions need templates and sectoral benchmarks to assess DT project quality.

B5. Detailed diagnosis and mitigation pathway

B5 (regional infrastructure disparities) should be interpreted beyond nominal internet coverage. Firms emphasize quality dimensions: reliability, latency, service disruptions, and the availability of specialized providers. In regions, even modest disruptions can undermine e-commerce operations and cloud-based workflows.

Mitigation requires targeted network reliability investments and local ecosystem development. Creating regional 'digital hubs'—combining broadband upgrades, shared co-working and training spaces, and local service provider networks—can raise returns to infrastructure spending.

B6. Detailed diagnosis and mitigation pathway

B6 (legacy systems and interoperability) is a mid-stage barrier. As firms adopt multiple digital tools, integration becomes the determinant of performance. Data silos and incompatible systems prevent automation and create duplicated work.

Mitigation is often managerial: define process owners, standardize data definitions, and adopt integration architectures (APIs, middleware). For larger firms, enterprise architecture capability becomes critical; for SMEs, standardized ERP and cloud solutions with interoperable modules can reduce complexity.

B7. Detailed diagnosis and mitigation pathway

B7 (cybersecurity readiness gaps) increasingly shapes DT decisions because digitization expands attack surfaces. Firms report concern about ransomware, data breaches, and business disruption. A single incident can reverse trust in digital channels.

Mitigation should be tiered. For SMEs, a minimum baseline (multi-factor authentication, backups, patching, endpoint protection, incident response checklist) delivers large risk reduction at manageable cost. For larger firms, maturity models and sectoral audits can guide improvements. Public programs can subsidize managed security services for SMEs.

B8. Detailed diagnosis and mitigation pathway

B8 (data governance and privacy uncertainty) becomes binding when firms start using customer data, analytics and cloud platforms. Without rules on data quality, access, retention and compliance, analytics initiatives produce unreliable results and increase legal risk.

Mitigation includes templates for data policies, standardized consent and documentation procedures, and training for data stewardship roles. Sector associations can provide shared guidelines to reduce firm-level design costs.

B9. Detailed diagnosis and mitigation pathway

B9 (organizational resistance to change) reflects the behavioural and cultural dimension of DT. Employees may fear job loss, increased monitoring, or disruption of established routines. Resistance can slow adoption and reduce realized benefits.

Mitigation requires change management: clear communication of benefits, involvement of staff in process redesign, phased rollouts, and training. Firms that treat DT as 'software installation' tend to face higher resistance and lower utilization. Leadership commitment and incentive alignment are necessary complements.

B10. Detailed diagnosis and mitigation pathway

B10 (limited strategic vision and leadership commitment) manifests when DT initiatives are not linked to business objectives and lack top management sponsorship. Projects then compete for resources and are easily de-prioritized.

Mitigation involves strategic alignment: define a DT portfolio tied to measurable KPIs (cost reduction, lead times, sales conversion, customer retention) and assign ownership. For SMEs, a simple DT strategy (1–2 pages) is often sufficient if it includes sequencing and resource allocation.

B11. Detailed diagnosis and mitigation pathway

B11 (regulatory and administrative complexity) affects DT through compliance uncertainty and fragmented standards. Even when firms are willing to digitize documentation and data exchange, lack of clarity on requirements can delay adoption.

Mitigation requires coordination: harmonize standards for electronic documents, data exchange and cybersecurity compliance, and ensure that SME support programs are coherent and accessible. A 'single window' for DT support services can reduce administrative burden.

B12. Detailed diagnosis and mitigation pathway

B12 (limited advisory and support services) is an ecosystem barrier. SMEs often lack internal expertise to design and manage DT projects. Without accessible diagnostics and consulting, financing instruments can remain underused or misallocated.

Mitigation includes creating standardized diagnostics, subsidized consulting vouchers, and local DT support centers. International practice suggests that combining advisory support with financing increases adoption and reduces project failure.

Supplementary Table: Policy instrument mapping (illustrative)

Table S1 maps top-tier barriers to practical instruments, lead institutions and monitoring indicators. The table is illustrative and can be adapted to specific programs.

Barrier (tier)	Instrument examples	Lead / partners	Monitoring indicators (examples)
B1 Skills (Top)	Micro-credentials; apprenticeships; SME training vouchers; university–industry labs	MoE/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 and response times
B9 Change management (Top)	Executive training; DT clinics; peer learning networks	Business associations; universities; consulting providers	Share with DT owner; utilization rates of ERP/CRM modules

Table S1. Policy instrument mapping aligned with barrier priorities (illustrative).

Appendix C. Practical guidance for replicating the analysis in Excel (step-by-step)

C1. Create a worksheet with barriers as rows and criteria as columns (Impact, Feasibility, Cost/Risk). Enter expert median scores for each barrier under each criterion (1–9).

C2. Compute vector normalization for each criterion: for each column j, compute the square root of the sum of squares, then divide each cell by this value to obtain normalized r_i□.

C3. Enter criterion weights (e.g., 0.45, 0.30, 0.25). Multiply each normalized value by the weight to obtain v_i□.

C4. Determine the ideal solutions: for benefit criteria, take the column maximum as A^+ and minimum as A^-; for the cost criterion, take the column minimum as A^+ and maximum as A^-.

C5. Compute distances for each barrier: $S_i^+ = SQRT(SUM((v_i□ - A□^+)^2))$, $S_i^- = SQRT(SUM((v_i□ - A□^-)^2))$.

C6. Compute the closeness coefficient: $C_i = S_i^- / (S_i^+ + S_i^-)$. Rank barriers in descending order of C_i.

C7. Robustness: create alternative weight scenarios (e.g., increase feasibility weight by 10% and renormalize). Recalculate ranks and compute rank correlations using Excel's RANK and CORREL functions (or Spearman via ranks).

C8. Subgroup analysis: compute separate median scores for SMEs and large firms (or Baku vs. regions) and repeat steps C2–C6 for each subgroup to compare rank shifts.