

Converting Digital Transformation into Supply-Chain Efficiency: Capability-Based Mechanisms in Ghanaian Manufacturing Firms

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Abstract

Digital transformation is widely expected to improve manufacturing supply chains, yet its operational value may depend less on technology acquisition than on the organisational capabilities through which digital information is converted into coordinated and adaptive action. Drawing on Organisational Information Processing Theory and the Dynamic Capabilities View, this study examines a serial capability pathway linking digital transformation to supply-chain efficiency through supply-chain visibility, supply-chain integration and reconfiguration capability, while testing environmental uncertainty and internal digital capability as boundary conditions. A stratified firm-level survey yielded 200 usable responses from medium and large Ghanaian manufacturing firms. Composite-score path models were estimated with HC3 heteroskedasticity-consistent standard errors, bootstrapped indirect effects, formal discriminant-validity diagnostics and missing-data sensitivity analyses. Digital transformation was strongly associated with visibility ($\beta = 0.614, p < 0.001$); visibility was associated with integration ($\beta = 0.350, p < 0.001$); and integration was associated with reconfiguration capability ($\beta = 0.362, p < 0.001$). In the full efficiency model, visibility ($\beta = 0.268, p < 0.001$) and reconfiguration capability ($\beta = 0.254, p < 0.001$) remained significant, whereas integration and the direct digital transformation coefficient were not statistically distinguishable from zero. The serial indirect association was positive (effect = 0.030, 95% CI [0.014, 0.055]). HTMT values remained below 0.85, including 0.747 for digital transformation and internal digital capability, and focal-predictor VIFs remained below 3.6. Environmental uncertainty did not significantly moderate the digital transformation-efficiency relationship ($\beta = 0.119, p = 0.051$), and internal digital capability did not moderate the final relationship. Sensitivity analyses using stricter item-completion rules and complete-item cases preserved the substan-

tive pattern. The findings indicate that digital transformation is operationally valuable when it improves information visibility and supports adaptive reconfiguration rather than through technology adoption alone.

Keywords

Digital Transformation, Supply-Chain Efficiency, Supply-Chain Visibility, Supply-Chain Integration, Reconfiguration Capability, Ghanaian Manufacturing

1. Introduction

Digital transformation has become a central element of manufacturing and supply-chain strategy because digitally connected systems can accelerate information exchange, automate routine activities and support data-informed planning. Prior reviews and empirical studies show that integrated enterprise systems, internet-of-things applications, analytics and digital partner interfaces can improve information availability and operational responsiveness (Ben-Daya et al., 2019; Büyüközkan & Göçer, 2018; Kache & Seuring, 2017; Rad et al., 2022; Rejeb et al., 2020). Recent evidence further links enterprise digitalisation to supply-chain efficiency, stability, resilience and performance, although the strength of these relationships varies across firms, industries and institutional environments (Al Tera et al., 2024; Jiang & Wang, 2024; Kim et al., 2024; Yu et al., 2024; Zhao et al., 2023). This variation matters because acquiring software, platforms, sensors or analytics does not itself guarantee shorter fulfilment cycles, lower process waste or more productive use of inventory and logistics resources.

The central problem is therefore one of operational conversion. Digital technologies enlarge the quantity, speed and accessibility of information, but firms still require organisational mechanisms that transform information into coordinated decisions and changed routines. Digital-transformation research increasingly rejects a simple technology-performance assumption and instead treats digital transformation as a process of organisational redesign, capability development and strategic renewal (Nambisan et al., 2017; Vial, 2019; Warner & Wäger, 2019). In supply chains, this argument is reinforced by studies showing that the performance value of digitalisation is mediated by visibility, information exchange, responsiveness, agility, resilience and related capabilities (Al Tera et al., 2024; Wei et al., 2025; Zaid et al., 2025; Zhao et al., 2023). However, much of this literature relies on broad outcomes such as overall supply-chain performance, resilience or firm performance. Such outcomes do not isolate whether digital transformation improves the efficiency with which supply-chain activities are executed.

Supply-chain efficiency is a more specific operational outcome, encompassing timely order fulfilment, efficient inventory use, cost-effective logistics, reduced process delays and avoidance of operational waste. Supply Chain 4.0 research highlights the need to distinguish operational efficiency from broader strategic or sustaina-

bility outcomes (Dahinine et al., 2024; Govindan et al., 2022). Research on inventory turnover, order fulfilment and timing likewise demonstrates that efficiency is anchored in time, quantity, flow and resource utilisation rather than in a general perception of organisational success (Wan et al., 2024). The present study therefore treats supply-chain efficiency as a distinct operational outcome.

The mechanism linking digital transformation to efficiency remains underdeveloped when visibility, integration and reconfiguration are combined into a single broad capability or examined without a coherent sequence. Visibility concerns what managers can see; integration concerns how information and decisions are coordinated across functions and partners; and reconfiguration concerns whether routines and resources can be altered in response to emerging conditions. Treating these as distinct capabilities permits a more precise explanation of digital value. Organisational Information Processing Theory explains why uncertain and interdependent supply chains require timely, accurate and accessible information for coordination (Galbraith, 1974; Srinivasan & Swink, 2018), whereas the Dynamic Capabilities View explains why information becomes valuable when firms can alter routines and redeploy resources in response to changing conditions (Teece, 2007; Warner & Wäger, 2019).

Ghanaian manufacturing provides a useful context because firms operate across heterogeneous industries and ownership structures and face uneven digital infrastructure, supplier concentration, logistics constraints and market uncertainty. The national establishment structure is also dominated by micro and small firms (Ghana Statistical Service, 2017), making medium and large manufacturers a comparatively distinctive organisational population in which formal supply-chain functions and digital systems are more likely to be observable. The sample covers food and beverages, consumer goods, chemicals, plastics, construction materials and light industrial products, providing variation in technological intensity and operational complexity.

The study asks: through which informational, coordinative and adaptive capabilities is digital transformation associated with supply-chain efficiency among Ghanaian manufacturing firms? It contributes in three respects. First, it distinguishes visibility, integration and reconfiguration as sequential informational, coordinative and adaptive mechanisms rather than interchangeable indicators of one generic digital capability. Second, it tests a specifically defined serial indirect association from digital transformation through visibility, integration and reconfiguration to efficiency. Third, it evaluates environmental uncertainty and internal digital capability as boundary conditions while treating unsupported moderation as theoretically informative rather than suppressing it.

2. Theoretical Background and Hypothesis Development

2.1. Digital Transformation and Supply-Chain Efficiency

Digital transformation extends beyond digitising individual records or automating isolated tasks. In supply chains, it involves redesigning information flows, plan-

ning processes, decision rights and inter-firm interfaces through interconnected digital technologies. Real-time monitoring, integrated enterprise systems, analytics, digital partner interfaces and automated workflows can improve the speed and quality of operational decisions (Büyüközkan & Göçer, 2018; Kache & Seuring, 2017; Vial, 2019). Internet-of-things and sensor technologies are especially relevant because they create near-real-time operational data that can improve monitoring, traceability and coordination (Ben-Daya et al., 2019; Rejeb et al., 2020). Big-data analytics likewise contributes to performance when analytical resources are aligned with business strategy and embedded in organisational capabilities (Akter et al., 2016; Wamba et al., 2017).

Although digital transformation can be positively related to efficiency, the study does not assume that a direct relationship will necessarily remain once capability mechanisms are modelled. The direct digital-transformation coefficient is therefore retained in the full model as an empirical benchmark rather than as the central theoretical claim.

2.2. Information Processing, Visibility and Integration

Organisational Information Processing Theory proposes that organisations facing uncertainty and interdependence must develop sufficient capacity to acquire, interpret and distribute information (Galbraith, 1974). Manufacturing supply chains face demand variation, lead-time uncertainty, production disruptions, inventory imbalances and logistics exceptions. When operational information is late, incomplete or fragmented, planning quality deteriorates and coordination costs rise. Digital transformation can increase information-processing capacity through real-time data, shared dashboards, integrated databases and analytical tools (Kache & Seuring, 2017; Srinivasan & Swink, 2018).

Supply-chain visibility is the ability to access timely, accurate and usable information about orders, inventory, demand, disruptions and logistics flows. Connected systems should strengthen visibility because they reduce informational delays and make exceptions more observable. Accordingly, H1: Digital transformation is positively associated with supply-chain visibility.

Visibility does not itself ensure coordinated action. Integration concerns the alignment of planning, information exchange and decision-making across procurement, production, logistics and external partners. A consistent view of orders, capacity, demand and disruption should reduce duplicated work and contradictory decisions. Accordingly, H2: Supply-chain visibility is positively associated with supply-chain integration.

2.3. Reconfiguration Capability as an Operational Conversion Mechanism

The Dynamic Capabilities View holds that performance differences arise not only from resources but from the ability to sense, seize and transform in changing environments (Teece, 2007). Digital systems can reveal bottlenecks and changing

demand, but they cannot by themselves redesign production sequences, revise inventory rules or redeploy resources. Reconfiguration capability captures the firm's ability to alter processes, routines, decisions and resource allocations in response to operational conditions. Studies of digital transformation and big-data analytics increasingly show that digital resources create value through dynamic capabilities rather than technological possession alone (Wamba et al., 2017; Vial, 2019; Warner & Wäger, 2019).

Integration should support reconfiguration because coordinated functions and partners can implement process changes more consistently. Reconfiguration, in turn, should improve efficiency by enabling firms to remove bottlenecks, reallocate capacity, revise fulfilment priorities and adjust supplier or logistics arrangements. The following hypotheses are therefore proposed: H3: Supply-chain integration is positively associated with supply-chain efficiency. H4: Supply-chain integration is positively associated with reconfiguration capability. H5: Reconfiguration capability is positively associated with supply-chain efficiency.

The central mediation proposition concerns the complete capability sequence rather than an unmodelled direct digital transformation-to-reconfiguration path. H6: Digital transformation has a positive serial indirect association with supply-chain efficiency through supply-chain visibility, supply-chain integration and reconfiguration capability.

2.4. Boundary Conditions

Environmental uncertainty may increase the operational value of digital transformation because volatile demand, supply conditions and operating constraints raise the need for rapid information processing and adaptive response. Digital systems may therefore have stronger efficiency associations when uncertainty is high, although severe uncertainty may also overwhelm firms whose routines cannot absorb additional information (Ivanov & Dolgui, 2020; Srinivasan & Swink, 2018; Wei et al., 2025; Wieland, 2021). H7: Environmental uncertainty positively moderates the association between digital transformation and supply-chain efficiency.

Internal digital capability refers to employees' digital skills, system competence and ability to apply digital tools. Firms with stronger capability may be better positioned to integrate technologies into operational routines. Enterprise digital capability has been linked with supply-chain digitalisation and cooperation capability (Chen & Tang, 2024), while digital-transformation research emphasises managerial and organisational capability in converting technologies into value (Vial, 2019; Warner & Wäger, 2019). H8: Internal digital capability positively moderates the association between digital transformation and supply-chain efficiency.

2.5. Conceptual Model

Figure 1 distinguishes the direct structural paths from H6, which is defined as the full serial indirect pathway $DT \rightarrow VIS \rightarrow INT \rightarrow REC \rightarrow EFF$. Environmental un-

certainty and internal digital capability are modelled as moderators of the digital transformation-efficiency association.

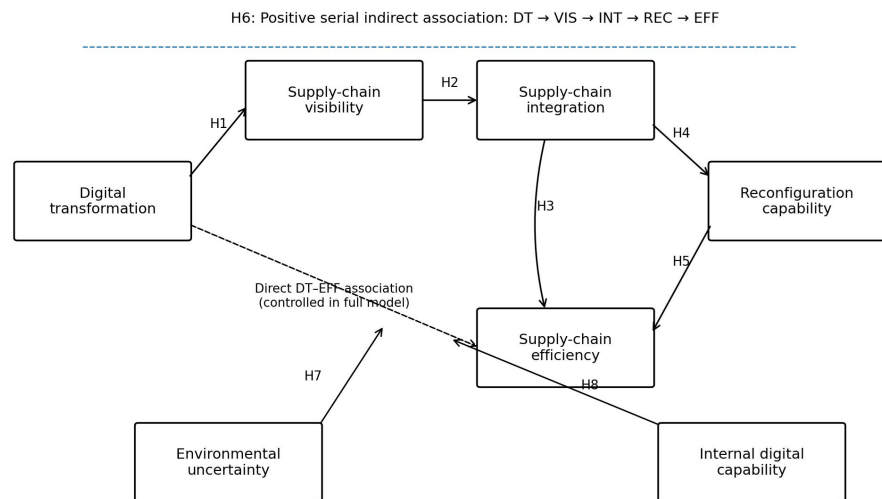


Figure 1. Conceptual framework.

3. Materials and Methods

3.1. Research Design, Sampling Frame and Recruitment

The study employed a cross-sectional explanatory survey design at the firm level. The target population comprised medium and large manufacturing firms with identifiable procurement, production, inventory, logistics or distribution activities and at least three years of operation. The unit of analysis was the firm. Because the purpose was to test theory-led associations among organisational constructs rather than establish temporal causation, all effects are interpreted as contemporaneous associations.

A working sampling frame was assembled from publicly accessible manufacturing-company listings and industry-association directories and classified using the industry and firm-size categories commonly used in Ghana's establishment statistics. Entries were de-duplicated and screened by telephone or company website to confirm manufacturing activity, firm size and the existence of formal supply-chain functions. This process produced a working frame of 536 eligible firms. A stratified recruitment plan targeted 200 usable cases across six industries, with allocations designed to preserve representation of the principal manufacturing categories while ensuring sufficient cases in smaller sectors. Within each sector, firms were approached systematically from the verified list until the target was reached.

A total of 320 firms were contacted. Two hundred and forty-six indicated willingness to participate, 214 returned sufficiently complete questionnaires, and 200 met all eligibility and data-quality requirements, yielding a usable response rate of 62.5% relative to firms contacted. The achieved distribution closely approximated the targeted industry allocation and the target split of 150 medium and 50 large

firms. The industry-specific sampling frame, recruitment targets and achieved usable responses are summarised in **Table 1**.

Table 1. Sampling frame, recruitment targets and achieved usable responses.

Industry stratum	Firms in working frame	Firms contacted	Targeted usable responses	Achieved usable responses
Food and beverages	132	80	50	51
Consumer goods	101	64	40	39
Light industrial	91	56	35	35
Plastics	78	48	30	33
Construction materials	69	40	25	25
Chemicals	65	32	20	17
Total	536	320	200	200

3.2. Key-Informant Selection and Respondent Profile

One knowledgeable informant was selected per firm to minimise ambiguity in the unit of analysis. Initial contact was made with the head of operations, supply chain, procurement, logistics, production planning or information systems. The preferred respondent had direct knowledge of the firm's digital systems and supply-chain routines and at least two years of organisational tenure. Where the initial contact did not meet these criteria, the firm was asked to nominate the manager or senior specialist with the broadest cross-functional knowledge of digital and supply-chain processes. No firm contributed more than one questionnaire to the analytical dataset.

Respondents represented supply-chain/procurement management, logistics and distribution, production and planning, operations/process improvement, and information-systems or digital-transformation functions. Mean organisational tenure was 7.1 years (SD = 4.3; median = 6), and 86.0% of respondents had at least three years' tenure, supporting their use as key informants for firm-level practices. The key-informant profile is summarised in **Table 2**.

Table 2. Key-informant profile.

Respondent role	n	%
Supply chain/procurement	64	32.0
Logistics/distribution	43	21.5
Production/planning	40	20.0
Operations/process improvement	31	15.5
Information systems/digital transformation	22	11.0
Total	200	100.0

3.3. Measures, Source Domains and Pilot Refinement

All focal constructs were measured on seven-point agreement scales ranging from 1 (strongly disagree) to 7 (strongly agree). Item wording was informed by established digital-transformation, information-processing, supply-chain visibility, integration, dynamic-capability and performance literatures and adapted to a manufacturing supply-chain context. Digital transformation was represented by five items; internal digital capability, visibility, integration, reconfiguration capability and environmental uncertainty by four items each; and supply-chain efficiency by five items. The full item wording, source domains and scoring rules are reported in Appendix A.

Before the main survey, the questionnaire was piloted with 12 managers drawn from eight manufacturing firms that were not included in the final sample. Pilot participants represented procurement, production, logistics and information-systems roles. The pilot led to four types of refinement: technical terms were simplified; double-barrelled statements were separated or removed; the distinction between digital-system deployment and employee digital capability was sharpened; and several items were anchored more explicitly to supply-chain operations. Predictor and outcome blocks were also separated in the questionnaire to reduce consistency-motif responding. The construct operationalisations and source domains are summarised in **Table 3**.

Table 3. Construct operationalisation and source domains.

Construct	Items	Operational definition	Source domain informing item pool
Digital transformation	5	Integrated digital systems supporting monitoring, planning, information sharing, automation and partner coordination.	Büyükoğkan & Göçer (2018); Vial (2019); Kim et al. (2024)
Internal digital capability	4	Employee digital skills, system competence and ability to use digital tools in operational work.	Chen & Tang (2024); Warner & Wäger (2019)
Supply-chain visibility	4	Timeliness, accuracy and accessibility of information on demand, inventory, orders and disruptions.	Williams et al. (2013); Srinivasan & Swink (2018)
Supply-chain integration	4	Coordination of planning, information exchange and decisions across functions and partners.	Jing & Fan (2024); Kim et al. (2024)
Reconfiguration capability	4	Ability to alter routines, processes, decisions and resource allocations as conditions change.	Teece (2007); Warner & Wäger (2019)
Supply-chain efficiency	5	Timely fulfilment, inventory efficiency, cost-effective execution and reduction of process waste.	Govindan et al. (2022); Wan et al. (2024)
Environmental uncertainty	4	Instability and unpredictability in demand, supply and the operating environment.	Srinivasan & Swink (2018); Wei et al. (2025)

3.4. Composite Scoring, Missing Data and Analytical Strategy

The raw dataset was preserved unchanged and all derived variables were generated reproducibly. Coding ranges, duplicate identifiers, missingness, descriptive

distributions and consistency between item-level responses and stored composite scores were checked. There were 115 missing item responses among 6000 potential item values (1.92%). For the primary analysis, a construct score was retained when at least half of its items were completed: at least three of five items for five-item scales and at least two of four items for four-item scales. All 200 firms met this rule. Construct scores were calculated as the arithmetic mean of available items, preserving the original one-to-seven metric.

Measurement quality was assessed using Cronbach's alpha, indicator loadings, composite reliability and average variance extracted (AVE). Discriminant validity was evaluated using the heterotrait-monotrait ratio (HTMT), with values below 0.85 treated as strong evidence of empirical distinction (Henseler et al., 2015). Because digital transformation and internal digital capability correlated at 0.702, their HTMT value and variance inflation factors (VIFs) were examined explicitly. Collinearity was assessed in the full moderation model after standardisation of the continuous predictors and construction of the product terms.

Structural relationships were estimated with standardised composite scores using ordinary least-squares path models and HC3 heteroskedasticity-consistent standard errors. Industry, ownership, employee size, firm age, and upstream and downstream concentration were included as controls. Moderation was assessed with product terms created from standardised variables. The serial indirect association was evaluated with 5000 non-parametric bootstrap resamples. Because the design is cross-sectional, indirect effects are interpreted as statistical indirect associations rather than temporal causal mediation.

Two missing-data sensitivity analyses were conducted. First, a stricter scoring rule required at least 75% of items for each scale (at least four of five items and at least three of four items), retaining 195 firms. Second, the structural models were re-estimated using only the 112 firms with complete responses on all 30 focal items. The purpose was to assess whether conclusions depended on available-item means.

4. Results

4.1. Sample Characteristics

As shown in Table 4, the 200 firms represented six manufacturing industries. Food and beverages formed the largest category (25.5%), followed by consumer goods (19.5%), light industrial products (17.5%), plastics (16.5%), construction materials (12.5%) and chemicals (8.5%). Most firms were locally owned (78.0%) and medium-sized (74.5%). Mean employment was 215.06 workers (SD = 175.19), and mean firm age was 22.45 years (SD = 11.23).

Table 4. Sample profile and firm characteristics.

Variable	Category	Frequency/Mean	Percentage/SD
Industry	Food and beverages	51	25.5
Industry	Consumer goods	39	19.5

Continued

Industry	Light industrial	35	17.5
Industry	Plastics	33	16.5
Industry	Construction materials	25	12.5
Industry	Chemicals	17	8.5
Ownership	Local	156	78.0
Ownership	Foreign	27	13.5
Ownership	Joint venture	17	8.5
Firm size	Medium	149	74.5
Firm size	Large	51	25.5
Continuous	Employees	215.06	175.19
Continuous	Firm age (years)	22.45	11.23

4.2. Descriptive Statistics and Correlations

As shown in **Table 5**, digital transformation and internal digital capability were moderately below the scale midpoint, whereas environmental uncertainty had the highest mean. The DT-IDC correlation of 0.702 warranted formal discriminant-validity and collinearity assessment rather than reliance on the correlation threshold alone.

Table 5. Descriptive statistics and construct correlations. DT = digital transformation; IDC = internal digital capability; VIS = supply-chain visibility; INT = supply-chain integration; REC = reconfiguration capability; EFF = supply-chain efficiency; EU = environmental uncertainty.

Variable	M	SD	DT	IDC	VIS	INT	REC	EFF	EU
DT	3.632	1.308	1.000						
IDC	3.808	1.244	0.702	1.000					
VIS	4.069	1.353	0.613	0.498	1.000				
INT	4.030	1.370	0.545	0.490	0.413	1.000			
REC	3.994	1.361	0.498	0.523	0.392	0.414	1.000		
EFF	4.123	1.373	0.538	0.507	0.532	0.420	0.522	1.000	
EU	4.715	1.137	-0.076	-0.040	-0.084	-0.075	0.012	0.003	1.000

4.3. Reliability, Convergent Validity and Discriminant Validity

As shown in **Table 6**, all constructs displayed strong internal consistency and convergent validity. Cronbach's alpha ranged from 0.891 to 0.957, composite reliability from 0.926 to 0.968, and AVE from 0.759 to 0.857. Indicator loadings were uniformly high. The first unrotated factor across all items explained 38.71% of variance; this diagnostic was treated as descriptive rather than as proof that common-method bias was absent.

Table 6. Reliability and convergent validity.

Construct	Loading range	Cronbach's α	Composite reliability	AVE	$\sqrt{\text{AVE}}$
Digital transformation	0.900 - 0.933	0.950	0.963	0.838	0.915
Internal digital capability	0.886 - 0.916	0.924	0.947	0.818	0.904
Supply-chain visibility	0.868 - 0.927	0.920	0.945	0.812	0.901
Supply-chain integration	0.875 - 0.939	0.934	0.955	0.840	0.917
Reconfiguration capability	0.909 - 0.924	0.937	0.956	0.845	0.919
Supply-chain efficiency	0.909 - 0.940	0.957	0.968	0.857	0.926
Environmental uncertainty	0.835 - 0.907	0.891	0.926	0.759	0.871

As shown in **Table 7**, the highest HTMT value was 0.747 for digital transformation and internal digital capability, below the conservative 0.85 criterion. The result supports empirical distinction between the constructs despite their relatively high zero-order correlation.

Table 7. HTMT discriminant-validity ratios. Values are based on item-level pairwise correlations; all are below 0.85.

	DT	IDC	VIS	INT	REC	EFF	EU
DT	—	0.747	0.645	0.568	0.523	0.562	0.082
IDC		—	0.523	0.517	0.568	0.545	0.043
VIS			—	0.434	0.406	0.566	0.097
INT				—	0.430	0.433	0.075
REC					—	0.546	0.039
EFF						—	0.042
EU							—

4.4. Collinearity Diagnostics

As shown in **Table 8**, the largest focal-predictor VIF was 3.557 for digital transformation. Although higher than the VIFs of the remaining constructs, it was below conventional levels indicating severe multicollinearity. Internal digital capability had a VIF of 2.373 and the DT $\times$ IDC interaction had a VIF of 1.204. Accordingly, the null moderation result is unlikely to be explained solely by excessive predictor collinearity.

Table 8. Focal-predictor VIFs in the full moderation specification.

Predictor	VIF
Digital transformation	3.557
Internal digital capability	2.373
Supply-chain visibility	1.801
Supply-chain integration	1.731

Continued

Reconfiguration capability	1.636
Environmental uncertainty	1.051
DT × environmental uncertainty	1.125
DT × internal digital capability	1.204

4.5. Structural Paths, Serial Indirect Association and Moderation

As shown in **Table 9**, digital transformation was strongly associated with visibility ($\beta = 0.614$, $p < 0.001$), supporting H1. Visibility was positively associated with integration ($\beta = 0.350$, $p < 0.001$), supporting H2, and integration was positively associated with reconfiguration capability ($\beta = 0.362$, $p < 0.001$), supporting H4. In the full efficiency model, reconfiguration capability ($\beta = 0.254$, $p < 0.001$) and visibility ($\beta = 0.268$, $p < 0.001$) remained significant. Integration did not retain an independent relationship with efficiency ($\beta = 0.059$, $p = 0.438$), so H3 was not supported, while H5 was supported.

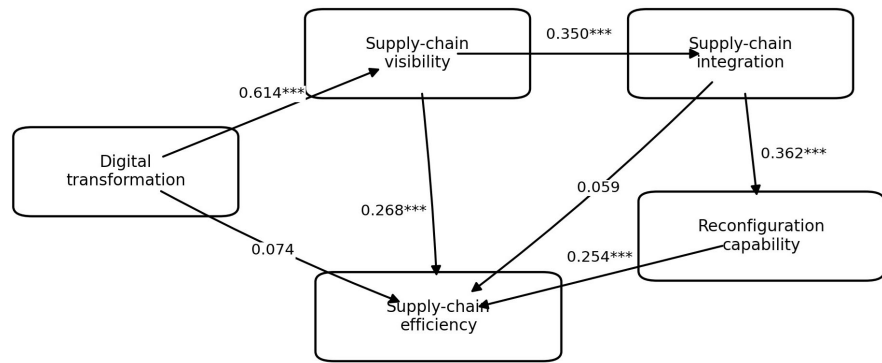
Table 9. Structural paths, serial indirect association and moderation.

Hypothesis	Path	β /effect	SE	p	95% CI	Decision
H1	DT → VIS	0.614	0.070	<0.001	[0.478, 0.750]	Supported
H2	VIS → INT	0.350	0.073	<0.001	[0.207, 0.492]	Supported
H3	INT → EFF	0.059	0.076	0.438	[-0.090, 0.207]	Not supported
H4	INT → REC	0.362	0.068	<0.001	[0.229, 0.496]	Supported
H5	REC → EFF	0.254	0.068	<0.001	[0.121, 0.387]	Supported
H6	DT → VIS → INT → REC → EFF	0.030	—	—	[0.014, 0.055]	Supported
H7	DT × EU → EFF	0.119	0.061	0.051	[-0.000, 0.238]	Not supported
H8	DT × IDC → EFF	0.043	0.050	0.382	[-0.054, 0.140]	Not supported

Consistent with H6, the estimated serial indirect association from digital transformation through visibility, integration and reconfiguration to efficiency was positive (effect = 0.030, 95% CI [0.014, 0.055]). This result supports the complete capability sequence rather than a direct DT → REC mediation claim. The direct digital-transformation coefficient in the full model was small and non-significant ($\beta = 0.074$, $p = 0.456$), indicating that the capability variables accounted for much of the observed association.

Environmental uncertainty produced a positive interaction that did not reach conventional statistical significance ($\beta = 0.119$, $p = 0.051$); H7 was therefore not supported. The interaction involving internal digital capability was not significant ($\beta = 0.043$, $p = 0.382$), and H8 was not supported. The full efficiency model explained 47.4% of the variance. **Figure 2** summarises the estimated structural rela-

tionships, while **Figure 3** displays the conditional digital transformation-efficiency slopes across environmental uncertainty.



Standardised coefficients; HC3 robust standard errors; * $p < .05$, ** $p < .01$, *** $p < .001$.

Figure 2. Estimated structural relationships.

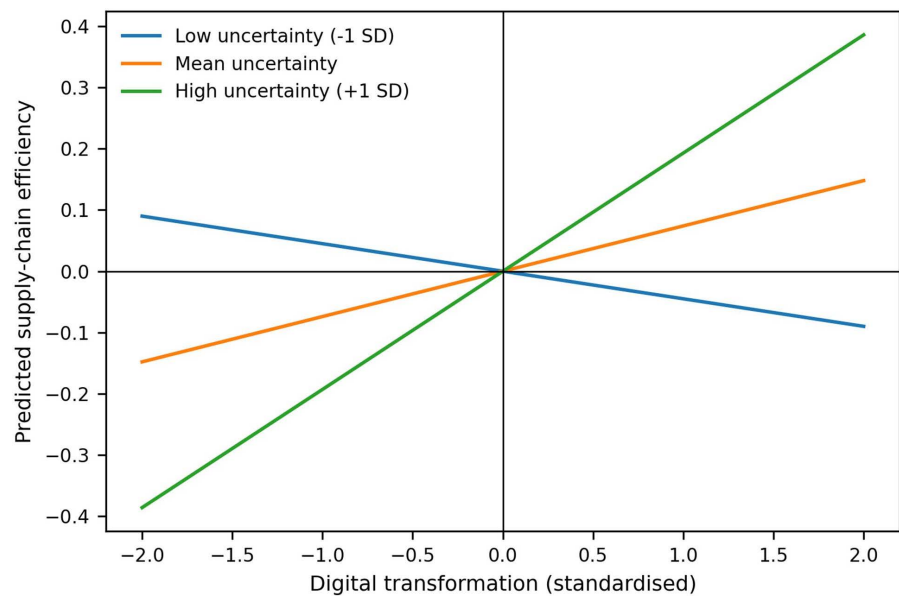


Figure 3. Conditional digital transformation-efficiency slopes across environmental uncertainty.

4.6. Missing-Data Sensitivity and Robustness

As shown in **Table 10**, the substantive conclusions were stable. Across the stricter 75% item-completion sample and the complete-item sample, the DT → VIS, VIS → INT, INT → REC, VIS → EFF and REC → EFF coefficients remained positive, whereas the independent INT → EFF relationship remained weak. The serial product was also positive in both sensitivity samples: approximately 0.0218 (bootstrap 95% CI [0.0069, 0.0475]) under the 75% rule and 0.0156 (95% CI [0.0018, 0.0470]) among complete-item cases. These checks indicate that available-item means were not responsible for the central findings.

Table 10. Missing-data sensitivity analysis. Coefficients were re-estimated using the same standardisation and control structure within each sensitivity sample.

Specification	N	DT → VIS	VIS → INT	INT → REC	DT → EFF	VIS → EFF	INT → EFF	REC → EFF	DT × EU	DT × IDC	R ²
Primary available-item scoring	200	0.616	0.353	0.369	0.103	0.271	0.057	0.258	0.119	0.046	0.470
≥75% item-completion rule	195	0.603	0.361	0.372	0.081	0.263	0.057	0.269	0.124	0.044	0.466
Complete on all 30 focal items	112	0.547	0.336	0.335	0.134	0.338	0.064	0.254	0.148	−0.067	0.497

5. Discussion

5.1. Main Findings

The study examined how digital transformation is translated into supply-chain efficiency. The results provide a clearer answer to the “how” question than to the “when” question. Digital transformation was strongly associated with visibility; visibility was associated with integration; and integration was associated with re-configuration capability. Yet only visibility and reconfiguration retained independent relationships with efficiency in the full model. The direct digital-transformation association weakened and became statistically non-significant once these capabilities were considered.

This pattern challenges a technology-centred interpretation of digital transformation. Firms may install integrated systems, dashboards or analytics without obtaining commensurate efficiency gains if the information does not improve operational visibility or enable reconfiguration of workflows and resources. The results are consistent with studies showing that visibility, information exchange, responsiveness, agility, survivability and resilience help explain digitalisation-performance relationships (Al Tera et al., 2024; Wei et al., 2025; Zaid et al., 2025; Zhao et al., 2023). The present study adds specificity by isolating operational efficiency and by modelling informational visibility, coordinative integration and adaptive reconfiguration as sequentially distinct mechanisms.

Integration’s unsupported direct relationship with efficiency is theoretically informative. Coordination may be necessary for reconfiguration but insufficient for efficiency when it remains procedural rather than action-oriented. Integration can align information and plans, but efficiency improvement may require managers to change production sequences, inventory rules, supplier arrangements or resource allocations. The positive integration-reconfiguration relationship and the serial indirect association are consistent with this interpretation.

5.2. Theoretical Implications

First, the findings refine Organisational Information Processing Theory by locating visibility as the primary informational return to digital transformation. Connected systems appear principally to increase the organisation’s capacity to observe demand, inventory, order and disruption conditions. Visibility then supports

integration, consistent with the premise that usable information is a precondition for coordinated decisions (Galbraith, 1974; Srinivasan & Swink, 2018).

Second, the study develops the Dynamic Capabilities View by showing that reconfiguration is a concrete operational conversion mechanism. Digital information becomes valuable when firms alter routines and redeploy resources. Reconfiguration remained a strong correlate of efficiency after digital transformation, visibility, integration and contextual factors were considered, adding operational specificity to the broader sensing-seizing-transforming logic (Teece, 2007; Warner & Wäger, 2019).

Third, H6 clarifies capability sequencing. The empirical proposition is not that reconfiguration alone mediates digital transformation. Rather, the tested serial association runs from digital transformation to visibility, from visibility to integration, from integration to reconfiguration, and from reconfiguration to efficiency. This sequencing aligns the hypothesis, conceptual model and statistical estimand.

Finally, the formal discriminant-validity evidence strengthens interpretation of the non-significant internal-digital-capability moderation. DT and IDC were correlated, but their HTMT ratio (0.747) and VIFs did not suggest empirical redundancy. The null interaction is therefore more plausibly interpreted as evidence that digital capability may operate earlier in the transformation process—as an antecedent of transformation or visibility—rather than amplifying the final DT-efficiency association.

5.3. Managerial and Policy Implications

Managers should evaluate digital transformation through the operational capabilities it creates. The first priority is visibility: systems should provide reliable, timely and accessible information about inventory, demand, fulfilment, transport and disruptions. Technology projects that produce additional data without improving decision visibility are unlikely to generate substantial efficiency gains.

Second, digital information should be linked to explicit coordination routines. Shared planning cycles, exception-management protocols and cross-functional decision rights can prevent visibility from remaining passive. Integration, however, should not be the endpoint. Managers need routines for process redesign, resource redeployment and rapid rescheduling so that coordinated information leads to operational change.

Third, firms should measure digital value with operational metrics such as order-cycle time, stockouts, inventory turnover, logistics cost, schedule adherence and process waste. For policy institutions and industry associations, support programmes should combine technology access with process redesign, data governance, interoperability and managerial capability building, particularly for medium-sized and locally owned manufacturers.

5.4. Limitations and Future Research

The study remains cross-sectional and therefore does not establish temporal or-

dering or causal mediation. Reverse causality is possible because efficient firms may have greater resources to invest in digital systems. Longitudinal studies should examine whether changes in digital transformation precede changes in visibility, reconfiguration and objective efficiency outcomes.

The focal variables were measured perceptually and largely within one survey. Procedural remedies, the single-factor diagnostic, discriminant-validity checks and collinearity analyses reduce specific concerns but cannot eliminate common-method bias (Podsakoff et al., 2024). Future research should combine manager surveys with system-generated data and objective indicators such as fulfilment time, inventory turnover, logistics cost and production downtime. Multi-informant and supplier-customer dyadic designs would improve construct separation and reduce same-source dependence.

The key-informant strategy is defensible for firm-level organisational practices but does not guarantee perfect organisational representation. Future studies should obtain paired responses from digital/IT and supply-chain managers and quantify inter-rater agreement. Finally, the strong reliability of several scales suggests some item similarity even though HTMT results support discriminant validity; future instrument development should retain conceptual breadth while avoiding redundant phrasing.

6. Conclusion

Digital transformation is neither an automatic route to efficiency nor merely a technological fashion. Among the Ghanaian manufacturing firms analysed, its operational value was associated chiefly with improved visibility and the capability to reconfigure routines and resources. Visibility supported integration, and integration supported reconfiguration, but integration did not independently predict efficiency after visibility and reconfiguration were included. The positive serial indirect association $DT \rightarrow VIS \rightarrow INT \rightarrow REC \rightarrow EFF$ provides a precise statement of the capability pathway linking digital transformation to supply-chain efficiency. Environmental uncertainty did not significantly strengthen the digital transformation-efficiency relationship, while internal digital capability did not strengthen the final relationship. The central implication is that digital systems create supply-chain value when firms use them to see operational conditions more clearly and to change operational arrangements more effectively.

Declarations

Ethical considerations and informed consent. Participation was voluntary. Respondents were informed of the academic purpose of the research, assured that responses would be treated confidentially and could discontinue participation. The analysis dataset contained no personally identifying information.

Data Availability

The anonymised firm-level dataset and analysis code may be made available by

the corresponding author upon reasonable request, subject to confidentiality commitments made to participating firms.

Author Contributions

K.A. and W.N.A. contributed to the conception and development of the study, interpretation of the findings, preparation of the manuscript and critical revision of its intellectual content. Both authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix A. Data Collection Instrument

Questionnaire Administration Notes

A single integrated key-informant questionnaire was used in this study.

The questionnaire was completed by one knowledgeable manager or senior specialist per firm with direct knowledge of the firm's supply-chain operations, digital systems, planning processes, logistics, procurement or operational coordination.

The selected key informant completed the full integrated questionnaire so that all focal constructs were measured for the same firm-level analytical case.

Appendix A1. Participant Information and Consent Form

This study examines whether digital transformation improves supply chain efficiency in manufacturing firms in Ghana, and whether this relationship operates through supply chain visibility, supply chain integration, and reconfiguration capability. It also considers whether environmental uncertainty and internal digital capability influence the strength of this relationship.

You have been invited because you hold a managerial role with direct knowledge of your firm's supply chain operations, digital systems, planning processes, logistics activities, procurement activities, or operational coordination.

You will be asked to complete one structured questionnaire covering your firm's supply-chain operations, digital systems and related organisational capabilities. The survey should take approximately 10 to 15 minutes.

Your participation is entirely voluntary. You may decline to answer any question, and you may withdraw before final submission of the questionnaire.

No personal names will be disclosed in any publication or report arising from this research. Firm names will be anonymised, and all responses will be used only for academic purposes.

There are no significant risks associated with participation beyond the time required to complete the questionnaire. Although there is no direct financial benefit, your participation may contribute to better understanding of how digital transformation affects supply chain efficiency in Ghanaian manufacturing firms.

Researcher contact

Researcher: [Insert Name]

Institution: [Insert Institution]

Email: [Insert Email]

Phone: [Insert Contact]

Consent statement

Please tick one option:

☐ I have read and understood the information above and agree to participate in this study.

☐ I do not agree to participate in this study.

Appendix A2. Response Scale

Unless otherwise stated, all items use the following response scale:

- 1 = Strongly disagree
- 2 = Disagree
- 3 = Somewhat disagree
- 4 = Neither agree nor disagree
- 5 = Somewhat agree
- 6 = Agree
- 7 = Strongly agree

Appendix A3. Integrated Key-Informant Questionnaire

Section 1. Firm and Respondent Identification

Please complete the following:

- 1) Firm code: _____
- 2) Respondent code: _____
- 3) Region/location: _____
- 4) Industry sector:
 - ☐ Food and beverages
 - ☐ Consumer goods
 - ☐ Chemicals
 - ☐ Plastics
 - ☐ Construction materials
 - ☐ Light industrial products
 - ☐ Other: _____
- 5) Your current position/title: _____
- 6) Years in current role:
 - ☐ Less than 1 year
 - ☐ 1 - 3 years
 - ☐ 4 - 6 years
 - ☐ 7 - 10 years
 - ☐ More than 10 years
- 7) Total years with this firm:
 - ☐ Less than 1 year
 - ☐ 1 - 3 years
 - ☐ 4 - 6 years
 - ☐ 7 - 10 years
 - ☐ More than 10 years

Section 2. Firm Profile and Control Variables

- 1) Number of full-time employees:
 - ☐ 30 - 49
 - ☐ 50 - 99
 - ☐ 100 - 149

☐ 150 - 249☐ 250 - 499☐ 500 or more

2) Age of firm:

☐ 3 - 5 years☐ 6 - 10 years☐ 11 - 15 years☐ 16 - 20 years☐ More than 20 years

3) Ownership structure:

☐ Fully Ghanaian-owned☐ Majority Ghanaian-owned☐ Majority foreign-owned☐ Fully foreign-owned☐ Joint venture

4) Main market orientation:

☐ Mainly local☐ Mainly national☐ National and export☐ Mainly export

5) Approximate proportion of annual sales to the largest customer:

☐ Less than 10%☐ 10% - 24%☐ 25% - 39%☐ 40% - 59%☐ 60% or more

6) Approximate proportion of major inputs sourced from the largest supplier:

☐ Less than 10%☐ 10% - 24%☐ 25% - 39%☐ 40% - 59%☐ 60% or more

Section 3. Supply Chain Visibility

Instruction: Please indicate the extent to which each statement reflects your firm's current operations.

Code	Item	1	2	3	4	5	6	7
SV1	We have timely visibility of inventory levels across key operational points.							
SV2	We can quickly track the status of customer orders through the supply chain.							
SV3	We receive early warning signals when supply or logistics disruptions occur.							
SV4	We have up-to-date visibility of demand changes affecting production and distribution.							

Section 4. Supply Chain Integration

Code	Item	1	2	3	4	5	6	7
SCI1	Different internal functions in our firm share operational information effectively.							
SCI2	Procurement, production, and logistics decisions are well coordinated in our firm.							
SCI3	We plan supply chain activities jointly across internal departments.							
SCI4	We exchange relevant operational information regularly with key suppliers.							

Section 5. Reconfiguration Capability

Code	Item	1	2	3	4	5	6	7
RC1	Our firm can quickly adjust operational routines when conditions change.							
RC2	We are able to reallocate resources rapidly when supply chain disruptions occur.							
RC3	We can redesign workflows when current processes no longer fit operational needs.							
RC4	Our firm responds quickly to unexpected changes in demand or supply conditions.							

Section 6. Supply Chain Efficiency

Code	Item	1	2	3	4	5	6	7
SCE1	Our order fulfilment process is completed efficiently.							
SCE2	Our inventory levels are managed with minimal unnecessary holding.							
SCE3	Our logistics activities are performed at an efficient cost level.							
SCE4	We experience fewer avoidable delays in supply chain execution.							
SCE5	Our production and distribution processes flow smoothly with limited waste.							

Section 7. Environmental Uncertainty

Code	Item	1	2	3	4	5	6	7
EU1	Customer demand in our market changes unpredictably.							
EU2	Supply conditions change frequently in ways that are difficult to anticipate.							
EU3	Market conditions affecting our operations are highly unstable.							
EU4	Our firm faces frequent changes in customer requirements.							

Section 8. Comparative Performance Anchors

1) Compared with key competitors, our order fulfilment speed is:

☐ Much lower

☐ Lower

☐ Slightly lower

☐ About the same

☐ Slightly higher

☐ Higher

☐ Much higher

2) Compared with key competitors, our supply chain operating cost efficiency is:

- ☐ Much lower
☐ Lower
☐ Slightly lower
☐ About the same
☐ Slightly higher
☐ Higher
☐ Much higher

Section 9. Digital Role Verification

1) Does your current role involve responsibility for any of the following?

- ☐ Digital systems
☐ ERP/MRP/planning systems
☐ Process digitalization
☐ Data analytics/reporting
☐ Operational technology
☐ Digital transformation projects

2) How familiar are you with your firm's digital systems used in supply chain operations?

- ☐ Very unfamiliar
☐ Unfamiliar
☐ Slightly unfamiliar
☐ Neutral
☐ Slightly familiar
☐ Familiar
☐ Very familiar

Section 10. Digital Transformation

Code	Item	1	2	3	4	5	6	7
DT1	Our firm uses integrated digital systems to coordinate major supply chain processes.							
DT2	Real-time operational data are available for important supply chain decisions.							
DT3	Our planning processes are supported by digital analytics or decision-support tools.							
DT4	Our digital systems enable data sharing across procurement, production, and logistics.							
DT5	We use digital technologies to improve coordination with supply chain partners.							

Section 11. Internal Digital Capability

Code	Item	1	2	3	4	5	6	7
IDC1	Our firm has the internal skills needed to use digital systems effectively.							
IDC2	Employees in relevant functions are capable of working with digital tools and data.							
IDC3	We can implement new digital solutions without major internal difficulty.							
IDC4	Our firm can solve operational problems arising from digital systems quickly.							

Section 12. Digital Adoption Profile

Please indicate the extent to which your firm currently uses each of the following in supply chain operations.

Response options:

1 = Not used

2 = Used in limited areas

3 = Used in several areas

4 = Widely used across operations

Item	1	2	3	4
ERP system				
MRP or production planning software				
Warehouse management system				
Transportation management system				
Barcode or RFID tracking				
IoT or sensor-based monitoring				
Real-time dashboards				
Business intelligence or analytics tools				
Supplier or customer digital portals				
AI-assisted forecasting or planning tools				

Section 13. Digital Maturity Indicators

1) Approximate number of years your firm has used integrated digital systems in supply chain operations:

☐ Less than 1 year

☐ 1 - 2 years

☐ 3 - 5 years

☐ 6 - 10 years

☐ More than 10 years

2) How would you rate your firm's overall digital maturity in supply chain operations?

☐ Very low

☐ Low

☐ Slightly low

☐ Moderate

☐ Slightly high

☐ High

☐ Very high

Appendix A4. Coding and Construct Mapping

Construct	Code prefix	Questionnaire section	Role in model
Digital Transformation	DT	Section 10	Exogenous predictor
Internal Digital Capability	IDC	Section 11	Moderator
Supply Chain Visibility	SV	Section 3	Mediator
Supply Chain Integration	SCI	Section 4	Mediator
Reconfiguration Capability	RC	Section 5	Mediator
Supply Chain Efficiency	SCE	Section 6	Outcome
Environmental Uncertainty	EU	Section 7	Moderator

Appendix A5. Hypothesis Mapping

Hypothesis	Path
H1	Digital Transformation → Supply Chain Visibility
H2	Supply Chain Visibility → Supply Chain Integration
H3	Supply Chain Integration → Supply Chain Efficiency
H4	Supply Chain Integration → Reconfiguration Capability
H5	Reconfiguration Capability → Supply Chain Efficiency
H6	Digital Transformation → Supply Chain Visibility → Supply Chain Integration → Reconfiguration Capability → Supply Chain Efficiency
H7	Environmental Uncertainty moderates the Digital Transformation → Supply Chain Efficiency relationship
H8	Internal Digital Capability moderates the Digital Transformation → Supply Chain Efficiency relationship