# Beyond Technology Adoption: An Integrated Framework of Digital Transformation in Manufacturing SMEs

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## ABSTRACT

Digital transformation can strengthen the productivity, quality, delivery reliability and resilience of manufacturing small and medium-sized enterprises (SMEs), yet the purchase of isolated digital applications does not necessarily produce organisation-wide change. This conceptual paper develops an integrated framework for explaining digital transformation adoption and translating the framework into a practical diagnostic and staged roadmap for manufacturing SMEs, with particular relevance to the Malaysian context. The paper synthesises the Technology–Organization–Environment (TOE) framework, the Theory of Planned Behaviour (TPB), the Unified Theory of Acceptance and Use of Technology (UTAUT), the Resource-Based View (RBV) and Dynamic Capabilities Theory. The core explanatory model retains perceived usefulness, perceived ease of use, technology readiness and top management support as antecedents of behavioural intention and digital transformation adoption, with behavioural intention proposed as a partial mediator. Environmental conditions including government support, customer requirements, supplier capabilities and digital ecosystems are treated as contextual influences, while cost, skills, cybersecurity and integration constraints are recognised as potential barriers. A comparative review of established readiness and maturity approaches informs an SME-oriented diagnostic tool comprising six dimensions: strategic and managerial direction; people and skills; technology and infrastructure; data and process integration; ecosystem connectivity; and value, risk and resilience. A five-stage roadmap is proposed, from foundational digitalisation to adaptive, data-driven transformation. Illustrative applications are provided for a small machine shop and a mid-sized exporter. As a conceptual study, the paper does not report empirical validation or claim universal applicability. It contributes a theory-grounded set of propositions and a practical structure for subsequent expert assessment, Delphi validation, case studies and survey testing using structural equation modelling. The framework is intended as a context-sensitive guide for managers and policymakers rather than a one-size-fits-all maturity standard.

**Keywords**: digital transformation, manufacturing SMEs, technology readiness, behavioural intention, digital maturity

## INTRODUCTION

Digital transformation (DT) has become an important strategic issue for organisations seeking to improve operations, respond to changing markets and create value through digitally enabled products and services. It is broader than digitisation, which converts analogue information into digital form, and digitalisation, which applies digital technologies to improve existing activities. DT involves changes to organisational processes, structures, capabilities and value creation (Vial, 2019; Verhoef et al., 2021). For manufacturing small and medium-sized enterprises (SMEs), this distinction matters because the introduction of accounting software, digital payments or a stand-alone production application may improve an individual task without integrating information or changing how the enterprise operates.

Manufacturing SMEs can use digital technologies to improve production planning, inventory visibility, quality monitoring, traceability, maintenance, procurement and customer coordination. Cloud systems, enterprise resource planning (ERP), industrial Internet of Things (IIoT), analytics and digitally connected equipment may

support better operational decisions. However, the benefits depend on the fit between technology and the firm's processes, infrastructure, workforce capabilities and strategic priorities. Studies of Industry 4.0 adoption in SMEs identify resource limitations, implementation complexity, skills shortages and uncertainty about returns as material challenges (Masood & Sonntag, 2020; Berrio et al., 2022).

The Malaysian context makes this issue particularly relevant. National initiatives such as Industry4WRD have sought to encourage manufacturing digitalisation, while Malaysian studies have examined SME readiness and Industry 4.0 adoption (Khin & Kee, 2022; Shahzad et al., 2023). Nevertheless, the availability of support programmes or technologies should not be interpreted as evidence that all SMEs have achieved meaningful transformation. SMEs differ in size, production complexity, export exposure, customer requirements, digital skills and financial capacity. A small jobbing machine shop and a mid-sized exporter may therefore require different starting points and investment sequences.

The original version of this paper proposed an integrated adoption model comprising perceived usefulness (PU), perceived ease of use (PEOU), technology readiness (TR), top management support (TMS), behavioural intention (BI) and digital transformation adoption (DTA). It combined TOE, TPB and UTAUT and developed thirteen propositions. The present revision retains that explanatory core but responds to the need for clearer construct definitions, stronger theoretical grounding, comparison with existing maturity models and practical guidance for implementation. It also makes explicit the role of external stakeholders and the constraints that can interrupt the transition from intention to implementation.

Five research questions guide the revised conceptual development: (1) How do PU, PEOU, TR and TMS relate to BI and DTA? (2) How does BI help explain the relationship between these antecedents and DTA? (3) How do external ecosystem conditions and SME-specific barriers shape the transformation context? (4) How can the explanatory framework be translated into a diagnostic and staged roadmap? and (5) How should the proposed relationships and diagnostic approach be validated in future research?

The paper makes three bounded contributions. First, it clarifies the complementary roles of technology evaluations, organisational resources and managerial commitment in explaining adoption. Second, it distinguishes an explanatory adoption model from a practical maturity diagnostic, avoiding the assumption that the same constructs automatically constitute a complete maturity scale. Third, it proposes an SME-oriented application pathway that can be adapted to different manufacturing contexts and evaluated empirically. The paper does not claim that the individual constructs are new or that the proposed framework has already been validated.

## Conceptual Development Approach

This paper uses a theory-informed conceptual development approach. The original manuscript and its cited literature provide the starting point for the six-construct adoption model. Additional theoretical perspectives and established readiness or maturity approaches are used to strengthen the explanation and practical application. The comparison is a focused conceptual synthesis rather than a systematic review: no exhaustive database search, protocol registration, screening flow or formal quality appraisal is claimed. Accordingly, the comparison table is intended to identify design characteristics and positioning, not to rank every model available.

The conceptual development proceeded in four steps. First, the focal constructs were defined and separated by level and function. Second, TOE, TPB, UTAUT, RBV and Dynamic Capabilities Theory were mapped to the relationships they can explain. Third, established digital readiness and maturity models were compared in terms of scope, dimensions, assessment logic and potential SME usability. Fourth, the resulting concepts were translated into an indicative diagnostic checklist and staged roadmap. The propositions remain theoretical expectations for future testing.

# LITERATURE REVIEW AND CONSTRUCT DEFINITIONS

## Digital transformation adoption in manufacturing SMEs

In this paper, DTA is defined as the extent to which a manufacturing SME has implemented and embedded digital technologies in relevant business and operational processes. It includes breadth of implementation, routine use, process integration and the use of digital information in operational decisions. It is not measured by awareness, intention, purchase alone or the number of software licences. This definition follows the view that transformation entails organisational change rather than technology acquisition alone (Vial, 2019; Verhoef et al., 2021).

Possible manifestations include digitally supported production scheduling, electronic work orders, integrated inventory records, machine or process data capture, digital quality records, customer order visibility, supplier coordination and management dashboards. The relevant indicators depend on the firm's production model. A small workshop may achieve meaningful transformation through reliable job tracking, digital maintenance records and inventory control; it need not begin with robotics or a fully automated smart factory.

Operational outcomes are important but conceptually distinct from DTA. Productivity, quality, delivery performance and resilience are potential consequences against which transformation may be evaluated. Productivity may be assessed through output per labour hour, machine utilisation or cycle time; quality through defect and rework rates; delivery through on-time-in-full performance and lead time; and resilience through recovery time, continuity of operations and the ability to respond to supply or demand disruptions. These outcomes are proposed for future evaluation, not claimed as effects established by this conceptual paper.

## Perceived usefulness

PU refers to the degree to which a decision-maker believes that a digital technology will improve task or organisational performance (Davis, 1989). In manufacturing SMEs, expected benefits may include lower production lead time, improved inventory accuracy, reduced scrap, improved traceability, faster quotation, better customer response or more reliable management information. PU captures expected value, not the firm's actual capability to realise that value. A manager may regard an ERP system as useful while the enterprise lacks clean data, trained employees or funds to implement it.

## Perceived ease of use

PEOU refers to the degree to which a decision-maker believes that using a particular technology will be relatively free of effort (Davis, 1989). In the manufacturing context, perceived effort includes learning, operation, configuration and the practical burden of integrating a system into existing routines. PEOU is not equivalent to implementation simplicity. A user-friendly application may still require substantial data migration, cybersecurity controls, equipment interfaces or workflow redesign. The distinction between perceived effort and objective integration complexity should be maintained in measurement.

## Technology readiness

TR is defined as the firm's preparedness to implement and sustain digital technologies. It includes adequate infrastructure, connectivity, equipment compatibility, data quality, technical support, employee digital skills, implementation resources and basic cybersecurity arrangements. TR is a firm-level enabling condition rather than an individual's optimism about technology. It is related to, but narrower than, overall digital maturity: readiness concerns preparedness to undertake a change, whereas maturity concerns the extent and sophistication of capabilities already embedded in the organisation (Hizam-Hanafiah et al., 2020; Amaral & Peças, 2021).

## Top management support

TMS refers to senior management's active commitment to digital transformation through strategic direction, investment decisions, communication, allocation of staff time, training, assignment of responsibilities and monitoring. Support is observable in decisions and follow-through, not merely verbal endorsement. In owner-

managed SMEs, the owner or managing director may directly shape investment priorities and organisational acceptance. TMS can therefore influence both the intention to proceed and the firm's ability to implement change.

**Behavioural intention**

BI refers to the decision-maker's stated willingness, plan or commitment to initiate or extend digital transformation within a defined period. TPB treats intention as a proximal antecedent of behaviour, while recognising that actual behaviour also depends on control and facilitating conditions (Ajzen, 1991). In this framework BI is measured at the decision-maker level, whereas DTA is a firm-level implementation outcome. Researchers must therefore explain how the respondent's intention represents the enterprise's decision process and, where feasible, triangulate it with other informants or documentary evidence.

**External ecosystem conditions and implementation barriers**

The external environment is relevant to SME transformation even though it is not an additional core antecedent in the original thirteen-proposition model. Government grants, tax incentives, advisory programmes, training and infrastructure can reduce the cost and capability barriers to adoption. Customers may require electronic ordering, product traceability, quality data, cybersecurity compliance or shorter response times. Suppliers and technology vendors can provide integration knowledge, maintenance, training and interoperable solutions. Industry associations, universities, technology centres and platform providers may form a digital ecosystem that gives SMEs access to capabilities they cannot economically maintain internally (Falahat et al., 2022; Cenamor et al., 2019).

**Theoretical Foundation And Integration**

**Technology–Organization–Environment framework**

TOE explains organisational innovation adoption through technological, organisational and environmental contexts (Tornatzky & Fleischer, 1990; Baker, 2012). In the proposed framework, PU and PEOU represent decision-makers' evaluations of technology attributes, while TR and TMS represent internal organisational conditions. The environmental context includes government support, customer and supplier demands, competitive pressure, infrastructure and ecosystem access. The original core model does not estimate environmental factors as separate antecedents; the revised paper therefore distinguishes the explanatory core from contextual extensions.

**Theory of Planned Behaviour and UTAUT**

TPB explains why intention is an important proximal predictor of behaviour while acknowledging that intention does not guarantee action when actual control is limited (Ajzen, 1991). This is particularly relevant to SMEs, where a positive intention may be interrupted by a lack of capital, skills, equipment compatibility or implementation time. UTAUT contributes the concepts of performance expectancy, effort expectancy and facilitating conditions (Venkatesh et al., 2003). PU and PEOU are conceptually related to performance and effort expectancy, but are not identical constructs. Similarly, TR and TMS contribute to the organisational conditions that make use feasible.

**Resource-Based View**

The RBV argues that differences in firms' resources and capabilities can explain differences in competitive advantage (Barney, 1991). For manufacturing SMEs, relevant resources include production knowledge, skilled employees, data, equipment, supplier relationships, financial resources and digital infrastructure. Digital transformation is not valuable simply because a firm owns technology; value depends on how the technology is combined with complementary resources and embedded in routines. RBV therefore strengthens the explanation of TR and TMS and helps explain why similarly available technologies may produce different outcomes across SMEs.

**Dynamic Capabilities Theory**

Dynamic capabilities concern the firm's ability to sense opportunities and threats, seize opportunities and reconfigure resources as conditions change (Teece et al., 1997). In an SME transformation journey, sensing may involve identifying bottlenecks or customer data requirements; seizing may involve selecting a feasible digital solution and allocating resources; and reconfiguring may involve redesigning workflows, retraining staff and integrating systems. Dynamic capabilities extend the framework beyond the initial adoption decision and provide a theoretical basis for staged learning, continuous improvement and adaptability.

**Socio-technical perspective**

A socio-technical perspective is also useful as an interpretive lens because digital transformation involves the joint adjustment of people, tasks, technology and organisational arrangements. A technology installation that ignores worker knowledge, job design, training or informal coordination may fail to become embedded in daily operations. This perspective supports the practical diagnostic dimensions of people and skills, process integration and management rather than treating technology as an isolated technical asset.

**Integrated theoretical logic**

The integrated logic is as follows. Technology acceptance perspectives explain whether decision-makers consider a digital solution valuable and manageable. TOE and RBV explain whether the enterprise has the internal and external conditions and resources required to act. TPB explains how favourable evaluations and enabling conditions may be associated with intention. Dynamic capabilities explain how the firm can convert initial implementation into continuing adaptation. The model therefore distinguishes adoption motivation, organisational feasibility and ongoing transformation capability. These theories are complementary, not interchangeable, and their constructs should not be collapsed into a single undifferentiated readiness measure.

**Comparison With Existing Digital Readiness And Maturity Models**

Existing readiness and maturity approaches provide useful precedents but differ in purpose, dimensions, assessment burden and intended users. The acatech Industrie 4.0 Maturity Index, for example, uses six stages from computerisation to adaptability and assesses resources, information systems, organisational structure and culture (Schuh et al., 2017). The IMPULS Industry 4.0 Readiness model uses six readiness levels and dimensions including strategy and organisation, smart factory, smart operations, smart products, data-driven services and employees (Lichtblau et al., 2015). A Malaysian conceptual model has also proposed a smart-manufacturing readiness and maturity approach tailored to SMEs (Rahamaddulla et al., 2021). The OECD's SME maturity work illustrates how digital maturity can be expressed through stages of technology adoption and digital culture (OECD, 2024).

Table 1. Comparison of Digital Readiness and Maturity Models

| Model / approach | Primary purpose and structure | Strength for SME use | Consideration for the present framework |
|---|---|---|---|
| IMPULS Industry 4.0 Readiness (Lichtblau et al., 2015) | Readiness assessment; six levels and six dimensions covering strategy, factory, operations, products, data-driven services and employees. | Structured self-assessment and manufacturing relevance. | Provides a strong comparison for readiness dimensions; the proposed framework adds explicit intention, managerial beliefs and an operational roadmap. |
| acatech Industrie 4.0 Maturity Index (Schuh et al., 2017) | Six maturity stages: computerisation, connectivity, visibility, transparency, predictive capacity and | Links maturity diagnosis to an individual | Technically rich and useful for manufacturing; the proposed approach seeks a lighter, SME- |

| | | | |
|---|---|---|---|
| | adaptability; four capability areas. | transformation roadmap. | adaptable diagnostic and includes ecosystem barriers. |
| Industry 4.0 readiness model review (Hizam-Hanafiah et al., 2020) | Review of 30 readiness models; identifies technology, people, strategy, leadership, process and innovation as recurring dimensions. | Shows recurring dimensions and variation across models. | Supports a multidimensional design; the present paper links diagnostic domains to a separate behavioural adoption model. |
| Malaysian smart manufacturing readiness-maturity proposal (Rahamaddulla et al., 2021) | SME-oriented conceptual model using Man, Machine, Management and Method attributes. | Explicitly considers Malaysian SME conditions and the need for accessible assessment. | The present paper complements this focus with explicit construct relationships, propositions, external ecosystem conditions and outcome indicators. |
| OECD SME digital maturity framework (OECD, 2024) | Staged maturity descriptions linking technology adoption and digital culture. | Accessible stage-based language and broad SME relevance. | The proposed diagnostic adds manufacturing-specific process, quality, delivery and resilience indicators. |
| Present integrated framework | Theory-grounded adoption model plus six-domain diagnostic and five-stage roadmap. | Combines decision-maker intention, organisational resources, external context and differentiated SME application. | Conceptual contribution is the integration and proposed application, not a claim that no comparable maturity model exists. |

The comparison indicates that the proposed framework should not be presented as a replacement for established maturity models or as a universally superior instrument. Its distinctive positioning is the combination of (a) an explanatory adoption model that distinguishes individual intention from organisational implementation, and (b) an SME-oriented diagnostic structure that can guide prioritisation and staged action. The six diagnostic domains are a proposed synthesis for future validation, not a validated scale at this stage.

**Proposition Development**

**Antecedents and digital transformation adoption**

PU may be associated with DTA because expected operational benefits strengthen the business case for investment and can influence the selection and implementation of relevant systems. PEOU may be associated with DTA because manageable technologies can reduce perceived learning and operating burdens. TR provides the infrastructure, skills and resources required for implementation, while TMS can authorise investment, assign responsibilities and resolve organisational barriers. These relationships are expected to vary with firm size, technology type and production complexity.

P1a: Perceived usefulness is positively associated with digital transformation adoption.

P1b: Perceived ease of use is positively associated with digital transformation adoption.

P1c: Technology readiness is positively associated with digital transformation adoption.

P1d: Top management support is positively associated with digital transformation adoption.

**Antecedents and behavioural intention**

PU may strengthen BI by making the expected operational and strategic benefits more compelling. PEOU may strengthen BI by reducing anticipated effort and disruption. TR may increase confidence that the firm can implement the proposed change, while TMS signals organisational priority and support. These mechanisms support the following propositions.

P2a: Perceived usefulness is positively associated with behavioural intention to adopt digital transformation.

P2b: Perceived ease of use is positively associated with behavioural intention to adopt digital transformation.

P2c: Technology readiness is positively associated with behavioural intention to adopt digital transformation.

P2d: Top management support is positively associated with behavioural intention to adopt digital transformation.

**Behavioural intention and adoption**

BI is expected to be positively associated with DTA because a decision-maker's commitment can initiate investment, planning and organisational action. However, the intention–implementation relationship is conditional on actual control, resources and the ability to overcome barriers. BI should therefore be interpreted as a motivational mechanism, not as a substitute for evidence of implementation.

P3: Behavioural intention is positively associated with digital transformation adoption.

**Mediating role of behavioural intention**

BI may partially mediate the relationships between the four antecedents and DTA. Favourable evaluations and organisational conditions may strengthen willingness to proceed, which is then associated with implementation. Direct paths remain because resources, infrastructure and management authority may facilitate adoption independently of an individual's stated intention. Empirical work should estimate each indirect effect and its confidence interval and should not infer temporal causality from a cross-sectional survey.

P4a: Behavioural intention positively mediates the relationship between perceived usefulness and digital transformation adoption.

P4b: Behavioural intention positively mediates the relationship between perceived ease of use and digital transformation adoption.

P4c: Behavioural intention positively mediates the relationship between technology readiness and digital transformation adoption.

P4d: Behavioural intention positively mediates the relationship between top management support and digital transformation adoption.

**Proposed Integrated Conceptual Framework**

Figure 1 presents the core adoption model and its contextual boundary. Solid arrows represent the thirteen propositions. The external ecosystem and implementation barriers are shown as contextual influences for interpretation and future extension; they are not additional tested paths in P1–P4 unless operationalised in a subsequent empirical study.

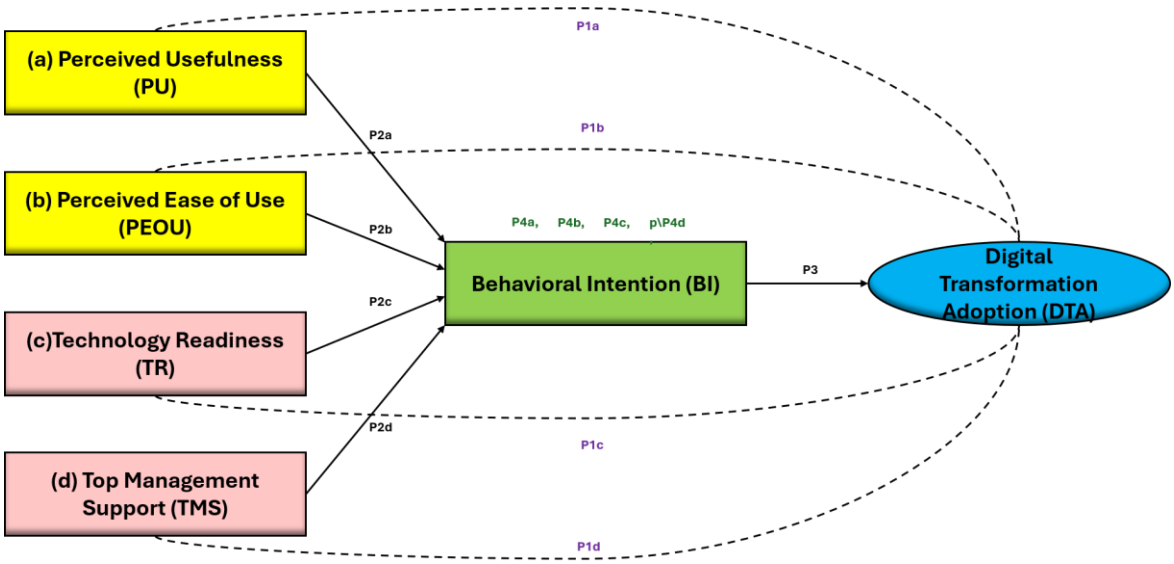
Figure 1. Integrated adoption framework and contextual boundary.

| | | |
|---|---|---|
| **TECHNOLOGY EVALUATIONS**<br>**PU**<br>**PEOU** | **BEHAVIOURAL INTENTION (BI)**<br>**P2a–P2d**<br><br>**P3 →** | **DIGITAL TRANSFORMATION ADOPTION (DTA)**<br>**P1a–P1d**<br><br>**P4a–P4d (indirect)** |
| **ORGANISATIONAL ENABLERS**<br>**Technology readiness (TR)**<br>**Top management support (TMS)** | **Intention pathway (motivational mechanism)** | **Firm-level implementation**<br>**Breadth • use • integration** |
| **CONTEXTUAL CONDITIONS (TOE ENVIRONMENT): Government support • customers • suppliers • digital ecosystem • competition IMPLEMENTATION BARRIERS: Capital cost • skills • integration • cybersecurity • time • legacy equipment** | | |

The four antecedents are conceptually distinct. PU and PEOU represent decision-maker evaluations; TR and TMS represent organisational enabling conditions; BI represents intention at the decision-maker level; and DTA represents firm-level implementation. This separation should be maintained in survey items and in the interpretation of results. External conditions may be examined in future research as controls, moderators or additional TOE variables, depending on the research question.

The conceptual diagram is deliberately static and does not model iterative learning, changing managerial intentions, technology replacement, organisational setbacks or exogenous shocks. Customer audits, supply-chain disruption, workforce turnover, financing constraints and regulatory requirements may change both the feasibility and perceived value of an initiative over time. The framework should consequently be treated as a time-bounded explanatory snapshot that can be re-estimated across stages, not a universal life-cycle theory. Its relevance outside Malaysian manufacturing SMEs, or across micro, small and medium firms, remains an empirical question.

Figure 2. Proposed integrated framework of digital transformation adoption in manufacturing SMEs




## Practical Application: Sme Diagnostic Checklist And Roadmap

### Purpose and use

The diagnostic component is designed as a structured managerial conversation and prioritisation tool. It is not a validated psychometric scale, certification scheme or universal ranking system. An SME can use it to identify current practices, select one or two operational problems, determine capability gaps and prepare a realistic

sequence of improvement. The assessment should be repeated periodically and adapted to the firm's products, process risks, customer requirements and available resources.

**Six diagnostic dimensions**

Table 2. Digital Transformation Diagnostic Checklist for Manufacturing SMEs

| Diagnostic dimension | Indicative questions / evidence | Possible improvement action |
|---|---|---|
| 1. Strategy and management | Is there a defined business problem and digital priority? Is an owner responsible? Is a budget or time allocation approved? Are expected benefits monitored? | Set one measurable business objective; appoint an accountable sponsor; define a small pilot and review date. |
| 2. People and skills | Can employees use the selected tools? Is training available? Are operators involved in workflow design? Is internal or external technical support accessible? | Provide role-based training; appoint a digital champion; use vendor, college or industry-association support. |
| 3. Technology and infrastructure | Are connectivity, devices, software, machine interfaces and backup arrangements adequate? Can legacy equipment be connected safely and economically? | Prioritise low-cost compatible tools; assess interoperability; plan staged replacement rather than wholesale automation. |
| 4. Data and process integration | Are job, inventory, quality, maintenance and customer records accurate? Are duplicate entries and manual hand-offs common? | Standardise master data; digitise priority records; integrate systems only after process and data discipline improve. |
| 5. Ecosystem and connectivity | Do customers require electronic orders, traceability or digital reporting? Can suppliers exchange data? Is support available from government, vendors or institutions? | Map key partner requirements; negotiate practical interfaces; explore relevant grants, training and shared services. |
| 6. Value, risk and resilience | Are benefits measured through productivity, defects, delivery and downtime? Are cybersecurity, access control, backups and recovery plans addressed? | Define baseline measures; conduct basic cyber hygiene; test backups and continuity arrangements; review value after pilot. |

**Indicative five-stage transformation roadmap**

Table 3. Five-Stage Digital Transformation Roadmap for Manufacturing SMEs

| Stage | Indicative position | Management focus | Illustrative evidence of progress |
|---|---|---|---|
| 1. Foundation | Basic records and isolated tools; processes remain mainly manual. | Identify a high-friction process; create a digital baseline; clarify ownership and risks. | Digital job or customer records; basic backups; one defined KPI. |
| 2. Connected basics | Selected functions use digital tools but data remain partly separate. | Improve connectivity and data consistency; train users; standardise processes. | Shared inventory or job status; electronic quality records; reduced duplicate entry. |

| | | | |
|---|---|---|---|
| 3. Integrated operations | Priority workflows and functions exchange reliable information. | Integrate production, inventory, purchasing and customer information where justified. | More accurate planning; traceability; fewer manual hand-offs; visible operational dashboard. |
| 4. Data-informed optimisation | Managers use timely data to analyse variation and improve performance. | Use analytics for quality, maintenance, scheduling and demand; strengthen cyber controls. | Evidence of reduced defects, downtime or lead time; regular data-led reviews. |
| 5. Adaptive ecosystem | The firm adjusts processes and collaborates digitally with key partners. | Develop predictive and adaptive capabilities; collaborate with suppliers and customers; review resilience. | Faster response to disruptions; partner integration; continuous improvement and new digital services. |

Progression is not necessarily linear. An SME may be advanced in quality traceability but basic in maintenance analytics. The roadmap should therefore be applied by process or capability area rather than assigning a single maturity label to the entire enterprise. Firms should not invest in advanced analytics or automation before establishing reliable data, clear process ownership and appropriate security controls.

**Indicative scoring approach**

For an initial self-assessment, managers may rate each checklist item on a five-point evidence scale: 1 = not in place; 2 = adhoc or dependent on individuals; 3 = defined and used in selected areas; 4 = integrated and regularly monitored; and 5 = optimised and improved using evidence. The score for each dimension may be calculated as the mean of its item ratings, provided the items are first reviewed for relevance. The result should be displayed as a profile across six dimensions, not combined into a single league-table score. A low score indicates an area for discussion, not a judgement of managerial competence. This scoring proposal is illustrative and requires content validation, reliability assessment and testing before being presented as a validated instrument.

**Illustrative application: small machine shop**

Consider a small machine shop with a limited number of employees, conventional machines, paper-based job cards and a small number of repeat customers. Its immediate business problems may be late job status updates, missing material records, unplanned machine downtime and difficulty estimating completion dates. A costly enterprise-wide ERP or advanced automation programme may be disproportionate at the outset. The diagnostic would likely prioritise management ownership, basic digital job tracking, inventory accuracy, machine maintenance records, employee training and secure backups. A feasible first project could digitise job orders and production status, then link material usage and quality records. Relevant outcomes would include schedule adherence, search time for job information, rework, inventory discrepancies and machine downtime. The example illustrates how a modest but integrated solution can be meaningful without requiring advanced automation.

**Illustrative application: mid-sized manufacturing exporter**

A mid-sized exporter may have several production lines, multiple customer accounts, supplier dependencies and formal requirements for quality records, delivery visibility and traceability. Its transformation priorities may include ERP and manufacturing execution integration, electronic supplier and customer interfaces, production analytics, cybersecurity governance and digital quality documentation. The diagnostic may identify fragmented systems, inconsistent master data, weak integration between planning and production, or insufficient cyber controls. A staged programme could begin with process and data standardisation, followed by integration of order, inventory and production information, then analytics for defect patterns and delivery reliability. The firm may also work with customers and suppliers to agree data standards and access controls. Relevant outcomes include on-time-in-full delivery, lead time, defect rates, traceability response time and recovery from supply interruptions.

The two examples demonstrate why a universal technology prescription is inappropriate. The same six diagnostic domains can be applied to both firms, but the evidence, target level and investment sequence should differ. Firm size alone should not determine the assessment: technology intensity, production complexity, customer requirements, risk exposure and existing capabilities also matter.

## Validation Strategy And Future Empirical Testing

### Expert review and Delphi validation

The first validation stage should assess content relevance and clarity. A panel could include manufacturing SME owners or managers, digital transformation consultants, manufacturing engineers, SME policy specialists and academic researchers in information systems or operations. Semi-structured interviews can examine whether the six diagnostic dimensions are understandable, whether any important domain is missing and whether the proposed checklist is feasible for SMEs with different resource profiles. A Delphi process may then be used to seek convergence on construct definitions, checklist items, stage descriptions and the relevance of proposed outcome indicators. Panel composition, recruitment, rounds, feedback procedures and consensus criteria should be reported transparently.

### Multiple case studies

A subsequent multiple-case study could purposively select SMEs with different sizes, manufacturing subsectors, digital starting points and export exposure. Data could be collected through interviews with owners, operations managers and employees, together with site observations and documentary evidence such as production records, quality reports and system screenshots. Cross-case analysis would examine how the adoption model and diagnostic roadmap operate under different conditions. Negative cases—firms with strong intention but limited implementation, or firms with adoption driven by customer requirements—would be especially informative.

### Survey and structural equation modelling

The thirteen propositions can subsequently be tested through a survey of manufacturing SMEs. The sampling frame should define SME eligibility, manufacturing activity and geographic scope. Respondents should be owners, directors or managers with direct knowledge of digital decisions and implementation. Established measurement items should be adapted rather than invented without justification. PU and PEOU should capture decision-maker perceptions; BI should capture intention; TR and TMS should capture organisational conditions; and DTA should capture actual implementation and integration. The survey should avoid asking about intention in the DTA items or asking about actual adoption in BI items.

PLS-SEM or covariance-based SEM may be considered depending on the study's prediction or theory-testing purpose, measurement model, distributional assumptions and sample characteristics. Sample size should be justified using an appropriate power analysis rather than a simplistic rule of thumb. Measurement assessment should include indicator reliability, internal consistency, convergent validity, discriminant validity and collinearity. Structural assessment should report path estimates, confidence intervals, explanatory power and effect sizes. Indirect effects should be assessed using bootstrapping. Common-method risk should be addressed through procedural design and suitable statistical diagnostics, while recognising that no single test eliminates the problem.

The cross-level issue requires particular attention. BI is ordinarily an individual response, while DTA is framed as a firm outcome. Researchers should justify the informant's authority and knowledge, consider multiple respondents where feasible, and triangulate DTA with objective or documentary indicators. A cross-sectional design can estimate associations and indirect effects but cannot establish temporal precedence or causal mediation. A longitudinal design that measures intention at an earlier point and implementation later would provide stronger evidence.

### Operational outcomes

Table 4. Operational Performance Indicators and Potential Data Sources

| Outcome domain | Illustrative indicators | Potential data source |
|---|---|---|
| Productivity | Output per labour hour; cycle time; machine utilisation; order processing time. | Production logs, time records, operational dashboards. |
| Quality | Defect rate; rework; scrap; customer complaints; traceability response time. | Quality reports, inspection records, customer returns. |
| Delivery performance | On-time-in-full delivery; order lead time; schedule adherence; late-order frequency. | Order management and delivery records. |
| Resilience | Downtime recovery time; continuity of critical operations; supplier disruption response; backup recovery test results. | Maintenance logs, incident reports, business continuity records. |

These outcomes should be treated as dependent performance variables in future studies, not as interchangeable indicators of DTA. Researchers may examine whether DTA is associated with operational outcomes and whether the relationship depends on firm resources, implementation quality, ecosystem support or transformation stage.

## DISCUSSION AND IMPLICATIONS

### Theoretical implications

The revised framework clarifies the division of explanatory work among the theories. TOE locates adoption in technological, organisational and environmental conditions. TPB explains the motivational link between intention and action. UTAUT offers complementary language for performance and effort expectations. RBV explains why complementary resources and firm-specific capabilities matter, while Dynamic Capabilities Theory explains how SMEs sense, seize and reconfigure resources over time. This integration offers a more complete account of why adoption may be attractive, feasible or difficult and why implementation may evolve unevenly.

A second implication is the separation between adoption explanation and maturity assessment. The six-construct model explains hypothesised relationships; the diagnostic domains organise practical evidence and improvement priorities. They are related but should not be treated as identical measurement models. This distinction avoids a conceptual error in which a manager's perceived usefulness or intention is used as a proxy for the firm's actual digital maturity.

A third implication concerns boundary conditions. The environmental context, external ecosystem and barriers may shape the strength or timing of the proposed relationships. However, the core model remains deliberately parsimonious. Future researchers can extend it by introducing government support, customer pressure, supplier integration or digital ecosystem capability as theoretically justified variables, rather than adding every possible factor to one model.

### Managerial implications

Managers should begin with an operational problem and a measurable business objective, not with a technology trend. A small pilot can test usefulness, usability, data requirements, employee acceptance and integration costs before wider investment. Managers should assess readiness realistically, provide time and training for employees, clarify responsibility and review outcomes after implementation. Digital transformation should be treated as an ongoing organisational change process rather than a one-off procurement.

### Policy and ecosystem implications

Policymakers and industry associations can use the framework to distinguish support for technology acquisition from support for capability development. Financial assistance may address initial capital constraints, while training, technical advice, shared test facilities, cybersecurity support and vendor-neutral guidance can help SMEs embed technology in their operations. Customer and supplier networks can also support transformation through interoperable data exchange, clear standards and collaborative problem-solving. Programme evaluation should measure implementation and operational outcomes, not only the number of firms receiving grants or purchasing software.

### Implications for manufacturing performance

The framework proposes that digital transformation may contribute to productivity, quality, delivery and resilience when technology is aligned with process needs and supported by people, management and ecosystem partners. It does not assume that all digital investments improve performance. Poorly selected systems, inadequate training, weak data quality or cybersecurity failures may create additional costs and operational risk. The practical diagnostic is intended to encourage a fit-for-purpose sequence and explicit benefit tracking.

### Limitations And Future Research

This paper is conceptual and reports no new empirical data. The propositions, diagnostic dimensions, scoring approach and roadmap have not been validated through expert panels, Delphi procedures, case studies or surveys. They should therefore be treated as proposals for investigation rather than established findings or a validated management instrument.

The literature synthesis is focused and theory-informed but is not a systematic review. It may not include all relevant readiness, maturity or digital transformation models. The comparison table is selective and should not be interpreted as exhaustive. A systematic review with explicit databases, search strings, inclusion criteria and quality appraisal would strengthen future claims about originality and model coverage.

The framework is oriented towards manufacturing SMEs and has particular relevance to Malaysia, but it should not be assumed to apply uniformly across countries, sectors or firm sizes. Regulatory environments, industrial infrastructure, customer expectations, labour markets and technology ecosystems differ. Even within manufacturing, a machine shop, food processor, electronics supplier and export-oriented producer may require different indicators and roadmaps.

The proposed core model also contains a cross-level relationship between individual BI and firm-level DTA. Future studies should address this through multi-informant designs, aggregation justification, documentary evidence or longitudinal measurement. Cross-sectional studies should avoid causal language and should report indirect effects as associations consistent with mediation rather than proof of a temporal mechanism.

Future research should validate the diagnostic dimensions through expert interviews and Delphi studies; conduct multiple case studies across manufacturing subsectors; test the thirteen propositions using appropriately powered surveys and SEM; and undertake longitudinal studies of transformation journeys. Cross-country comparisons could examine how institutional support, digital infrastructure and ecosystem maturity influence adoption. Practical toolkits, manager workbooks and sector-specific indicator banks should be developed only after iterative testing with SMEs.

## CONCLUSION

This paper revises and extends an integrated framework for digital transformation adoption in manufacturing SMEs. It retains PU, PEOU, TR and TMS as antecedents of BI and DTA and preserves the thirteen propositions describing direct, intention-related and indirect relationships. The theoretical explanation is strengthened through TOE, TPB and UTAUT, complemented by RBV and Dynamic Capabilities Theory. The revision also makes the

external ecosystem and SME implementation barriers explicit without treating them as tested constructs in the core model.

Beyond explaining adoption, the paper proposes a six-domain diagnostic and five-stage roadmap to help SMEs identify capability gaps and prioritise realistic improvement. The contrasting examples of a small machine shop and a mid-sized exporter illustrate why the same framework must be adapted to different operating conditions. The diagnostic, scoring approach and roadmap remain unvalidated and should not be represented as a universal standard. Their value depends on future expert review, case-based refinement and empirical testing across sectors and countries. The paper therefore offers a theory-grounded and practically oriented foundation for subsequent research and context-sensitive managerial use.

**Declarations**

Ethics statement: Not applicable. This is a conceptual paper and no new human-participant data were collected or analysed.

Conflict of interest: The authors declare no conflict of interest.

Data availability statement: Not applicable. No new dataset was generated or analysed for this conceptual paper.

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## REFERENCES

1. Ajzen, I. (1991). The theory of planned behavior. Organizational Behavior and Human Decision Processes, 50(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T
2. Amaral, A., & Peças, P. (2021). A framework for assessing manufacturing SMEs Industry 4.0 maturity. Applied Sciences, 11(13), 6127. https://doi.org/10.3390/app11136127
3. Baker, J. (2012). The Technology–Organization–Environment framework. In Y. K. Dwivedi, M. R. Wade, & S. L. Schneberger (Eds.), Information systems theory (Vol. 28, pp. 231–245). Springer New York. https://doi.org/10.1007/978-1-4419-6108-2_12
4. Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99–120. https://doi.org/10.1177/014920639101700108
5. Berrio, S. R., Rincon-Novoa, J., Sánchez-Monrroy, M., Ascúa, R., & Montoya-Restrepo, L. A. (2022). Factors influencing 4.0 technology adoption in manufacturing SMEs in an emerging country. Journal of Small Business Strategy, 32(3). https://doi.org/10.53703/001c.34608
6. Cenamor, J., Parida, V., & Wincent, J. (2019). How entrepreneurial SMEs compete through digital platforms: The roles of digital platform capability, network capability and ambidexterity. Journal of Business Research, 100, 196–206. https://doi.org/10.1016/j.jbusres.2019.03.035
7. Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly, 13(3), 319–340. https://doi.org/10.2307/249008
8. Falahat, M., Cheah, P. K., Jayabalan, J., Lee, C. M. J., & Kai, S. B. (2022). Big data analytics capability ecosystem model for SMEs. Sustainability, 15(1), 360. https://doi.org/10.3390/su15010360
9. Hizam-Hanafiah, M., Soomro, M. A., & Abdullah, N. L. (2020). Industry 4.0 readiness models: A systematic literature review of model dimensions. Information, 11(7), 364. https://doi.org/10.3390/info11070364
10. Khin, S., & Kee, D. M. H. (2022). Identifying the driving and moderating factors of Malaysian SMEs' readiness for Industry 4.0. International Journal of Computer Integrated Manufacturing, 35(7), 761–779. https://doi.org/10.1080/0951192X.2022.2025619
11. Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., et al. (2015). Industrie 4.0 readiness. IMPULS-Stiftung. https://impuls-stiftung.de/wp-content/uploads/2022/05/Industrie-4.0-Readiness-english.pdf

12. Masood, T., & Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. Computers in Industry, 121, 103261. https://doi.org/10.1016/j.compind.2020.103261
13. OECD. (2024). Advancing the digital transformation of Armenian businesses. OECD Publishing. https://www.oecd-ilibrary.org/foreword_d82c15d9-en.pdf?itemId=%2Fcontent%2Fcomponent%2Fd82c15d9-en&mimeType=pdf
14. Rahamaddulla, S. R. B., Leman, Z., Baharudin, B. T. H. T., & Ahmad, S. A. (2021). Conceptualizing smart manufacturing readiness-maturity model for small and medium enterprise (SME) in Malaysia. Sustainability, 13(17), 9793. https://doi.org/10.3390/su13179793
15. Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W. (2017). Industrie 4.0 maturity index: Managing the digital transformation of companies. acatech – National Academy of Science and Engineering. https://en.acatech.de/publication/industrie-4-0-maturity-index-managing-the-digital-transformation-of-companies/
16. Shahzad, A., Zakaria, M. S. A. B., Kotzab, H., Makki, M. A. M., Hussain, A., & Fischer, J. (2023). Adoption of fourth industrial revolution 4.0 among Malaysian small and medium enterprises (SMEs). Humanities and Social Sciences Communications, 10, Article 693. https://doi.org/10.1057/s41599-023-02076-0
17. Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. Strategic Management Journal, 18(7), 509–533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z
18. Tornatzky, L. G., & Fleischer, M. (1990). The processes of technological innovation. Lexington Books.
19. Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3), 425–478. https://doi.org/10.2307/30036540
20. Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. Journal of Business Research, 122, 889–901. https://doi.org/10.1016/j.jbusres.2019.09.022
21. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems, 28(2), 118–144. https://doi.org/10.1016/j.jsis.2019.01.003