The Differentiated Influence of Digitalization of United Kingdom Manufacturing Industry on Operational Performance-A Comparative Study of Large Enterprises and Small and Medium-sized Enterprises as an Example

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Abstract. Amid labour shortages, high energy costs and supply chain volatility, UK manufacturing is leveraging digitalisation to enhance operational performance and resilience. At the enterprise level, digital intensity correlates positively with productivity, with large enterprises leading Small and Medium-sized Enterprises (SMEs) in digital capital, data governance and system integration. The national 'Made Smarter' programme lowers barriers through diagnostics, funding and training, bolstering organisational capabilities. This paper compares multiple indicators to examine digital pathways and returns. Large enterprises prioritise master data governance and system interface cleansing, following a 'governance-first, compounding gains' trajectory. BAE Systems' 'Future Factory' and Rolls-Royce's digital twin initiatives demonstrate sustained improvements in lead times and Overall Equipment Effectiveness (OEE). SMEs follow a 'bottleneck prioritisation – visualisation – small-scale automation' approach, achieving localised improvements in First Pass Yield (FPY) and lead time reduction within 3-6 months. However, without comprehensive process and data governance, returns plateau during expansion phases. Predictive maintenance research underpins reduced downtime and stable delivery. This paper establishes linkages between metrics, mechanisms, and case studies, proposing reusable implementation sequences and key human-factor governance principles.

Keywords: Digital transformation, operations management, SMEs, OEE, made smarter.

1. Introduction

British manufacturing finds itself at a structural inflection point, grappling with multiple pressures. Post-Brexit trade frictions, energy price shocks and persistent global supply chain disruptions coexist with chronic skills shortages and labour constraints. Consequently, there is a marked increase in management demands for 'boosting productivity and delivery reliability' [1]. Within this macroeconomic context, recent corporate-level research indicates a significant positive correlation between digital adoption intensity and business productivity. Large enterprises generally lead in digital capital and data governance, thereby possessing stronger system integration and cross-site collaboration capabilities [1, 2]. Parallel to corporate behaviour, a dual-track 'innovation-adoption' mechanism has emerged at the national level around the Made Smarter initiative: on one hand, advancing key technological maturity and application demonstrations through research funding and experimental platforms; on the other, lowering adoption barriers at the regional level via diagnostics, subsidies, and mentoring to establish an institutionalised pathway 'from pilot to scale-up' [3-6].

Regarding the 'digitalisation-performance' relationship, management practice urgently requires an operationally verifiable analytical framework. This paper centres on three unified metrics: Lead Time (the number of days from order confirmation to delivery), FPY (the proportion of batches passing inspection on the first attempt), and OEE, defined as "Availability × Performance × Quality". Within this framework, the paper articulates the impact mechanism of digitalisation through three pathways: 'visualisation—standardisation—predictive capability'. These are mapped to process variables such as waiting time, changeover losses, rework cycles, and unplanned downtime [7, 8]. Subsequently, this paper compares systemic differences across enterprises of varying scales in investment structure, data governance, cross-functional collaboration, and payback periods, thereby explaining divergences in benefit curves and implementation pacing. Concurrently, it examines the dual leverage effect of initiatives like Made Smarter on time and capability—shortening payback periods through funding and external expertise while enhancing organisational endogenous capabilities via training and methodologies [3-6].

The research employs a qualitative comparative and case study design. For large enterprises, BAE Systems' 'Factory of the Future' and Rolls Royce's digital twin and health monitoring practices are selected to demonstrate end-to-end improvement pathways achieved through system integration, process digitisation, and predictive maintenance [7, 8]. For SMEs, multi-sector cases under the Made Smarter Adoption framework were selected, covering common entry points such as visualised production scheduling, automated quality inspection, and energy consumption monitoring. This illustrates the implementation sequence and effectiveness characteristics of the 'bottleneck-first, incremental automation' approach [5, 6, 9]. Data sources primarily comprise publicly available materials and government project evaluations, with case evidence predominantly consisting of directional statements. Despite the absence of uniformly calibrated raw operational data, aligning metrics and mechanism chains still provides comparability and operational feasibility for practice [10, 11].

This paper contributes to three respects. First, it offers a cross-scale comparative framework under unified metrics, transforming the generalised assertion that 'digitalisation matters' into a verifiable pathway addressing 'where to focus efforts, when to expect results, and which capabilities determine upper limits'. Second, it uses the mechanism chain as a thread to connect the differing benefit timelines of large enterprises and SMEs, offering an explanation for the choice between 'governance first—compound accumulation' and 'bottleneck prioritisation—incremental expansion'. Third, integrating dynamic capabilities and the TCP Offload Engine (TOE) framework, it proposes scale-specific implementation sequences and human-centred governance essentials, providing reference value for policy tool design and the pacing of corporate practices [12-14].

2. Literature Review

2.1. Section Headings

Existing research underpins the relationship between "digitalisation and operational performance" from both practical and theoretical perspectives. At the practical level, production and operations management literature commonly categorises the influencing pathways into three mechanisms. The first mechanism is visualisation, which reduces search and communication costs through data collection, kanban systems, and takt time management. This minimises delays caused by queuing and changeovers, thereby impacting the "performance" components of Lead Time and OEE [10]. The second mechanism is standardisation, which reduces rework cycles and quality fluctuations through work instructions, error-proofing, and parameter boundaries, thereby enhancing FPY and stabilising process capability. Standardisation, particularly in cross-process and cross-system environments, is mutually dependent with interface cleansing, determining the sustainability and replicability of improvements [10]. The third mechanism is predictability. Predictive maintenance, centred on condition monitoring and life cycle modelling, reduces unplanned downtime, elevates OEE's "availability" metric, and stabilises delivery schedules through planned maintenance windows [11].

Scale disparity presents another critical insight. Research based on UK enterprise-level data demonstrates a significant positive correlation between digital usage intensity and productivity, with larger enterprises generally exhibiting greater "digital density" [1, 2]. Large enterprises possess more mature Information Technology/Operational Technology (IT/OT) convergence and data governance capabilities, making them better equipped to bear upfront costs for master data governance and cross-system integration. This enables compounding improvement curves post-integration. In contrast, SMEs exhibit faster organisational responsiveness and lower path dependency, allowing rapid pilot deployment at bottleneck points for short-term gains. However, funding, human resources, and process maturity constitute primary constraints during scaling phases [9, 14].

Policy and project literature emphasise the dual ‘time-capability’ leverage of public intervention. Made Smarter reduces sunk costs for first-time adoption through enterprise diagnostics, micro-funding, and mentoring mechanisms, while enhancing internal capabilities via training and methodologies. UK Research and Innovation's final evaluation and government research summaries provide traceable evidence of project structure, metrics, and outcomes [3-6]. Concurrently, Made Smarter Innovation strengthens the coupling between technology and ecosystems through research and demonstration, providing technical and organisational environmental support for Adoption diffusion [3, 4].

Within explanatory frameworks, ‘dynamic capabilities’ emphasise enterprises' perception of opportunities, capture of resources, and reallocation of assets within complex environments. The interplay of these three factors determines sustained performance and the slope of the learning curve [12]. The TOE framework characterises adoption differences across three dimensions—technological maturity, organisational resources, and external environment—enabling explanations of the interactive effects of scale, industry processes, and policy support [13]. Systematic reviews concerning SMEs further indicate that funding constraints, data quality, and skill structures are common bottlenecks, yet flexible organisational structures and shorter decision-making chains provide scope for rapid piloting and iteration [14]. Overall, existing literature provides clear mediating variables at the mechanism level and differentiated constraints and drivers at the scale and policy levels. However, there remains scope for improvement in conducting ‘cross-case comparisons under a unified operational framework’ – precisely the focus of this paper.

3. Case Analysis

3.1. Large Enterprise Case Study: BAE Systems (Factory of the Future, Lancashire)

The research employs a combined qualitative comparative and case study design, with the UK manufacturing sector as its field of inquiry. Case selection adhered to the ‘representativeness-accessibility-comparability’ principle. For large enterprises, BAE Systems' ‘Factory of the Future’ (featuring end-to-end visualisation, flexible workstations, collaborative robots, and 5G) and Rolls Royce's digital twin and health monitoring practices (centred on life cycle management and predictive maintenance) were chosen to represent high-complexity, high-interdependence aerospace manufacturing scenarios [7, 8]. For SMEs, multi-sector enterprises with publicly available materials from the Made Smarter Adoption programme were selected, covering typical entry points such as visualised production scheduling, automated quality inspection, and energy consumption monitoring [5, 6, 9].

BAE's UK-built ‘Factory of the Future’ features digital connectivity, intelligent workstations, robots/collaborative robots, and 5G, emphasising end-to-end visibility and flexibility from design to assembly.

Workstation-level error-proofing and digital guidance reduce rework cycles; online monitoring and scheduling of equipment/fixtures minimise waiting and changeover times. Ultimately, these yields increased FPY, reduced lead times, and steadily improving OEE; however, upfront master data governance and interface cleansing determine the ceiling and sustainability of improvements (benefits are achieved in stages until cross-system integration is complete). Other enterprises leverage engine digital twins and health monitoring to integrate maintenance strategies with lifecycle management, enhancing planning and time-on-wing. By employing ‘high-frequency condition data + mechanism/data-driven models,’ they proactively identify degradation and advance maintenance windows, leading to reduced unplanned downtime.

These yields improved OEE and more stable delivery commitments; however, model and data engineering capabilities remain limiting factors. General evidence regarding predictive maintenance's impact on OEE/downtime improvements is detailed in the review.

3.2. SMEs: Made Smarter Adoption Case Studies (Multi-Industry)

Under the guidance of Made Smarter diagnostics and small-scale funding/training support, SMEs typically commence by addressing bottleneck areas (such as visualised production scheduling, automated quality inspection, and energy consumption monitoring), before progressively expanding to adjacent processes and cross-functional collaboration. The approach involves first rendering the 'invisible' visible (through data collection and kanban systems), then implementing small-scale automation/error-proofing, and finally addressing process and data governance. The ultimate outcomes typically manifest as reduced lead times and increased on-time delivery rates, alongside improvements in FPY. OEE improvements gradually emerge following process expansion and adjustments to maintenance strategies. Policy support and guidance play a pivotal role in lowering pilot project barriers and facilitating capability outsourcing.

4. Discussion and Management Recommendations

Large enterprises possess broader system boundaries and incur higher costs for interface and master data governance. However, once integrated, the compounding benefits from cross-line/cross-plant collaboration become significantly stronger; this aligns with productivity evidence at the corporate level. SMEs can achieve visible directional improvements within six months through a low-sunk-cost approach of 'bottleneck prioritisation – visualisation – small-scale automation'. Yet without addressing 'data/process governance', gains will eventually plateau. This divergence can be explained through the dynamic capability and TOE framework: scale and organisational capacity determine the depth and speed of perception-capture-reallocation.

Large enterprises follow a 'governance-first, compounding gains' improvement rhythm. Initially, resources are allocated to master data governance, interface cleansing, and process standardisation, with short-term benefits primarily manifested in reduced rework and information delays. Following end-to-end integration, the Plan–Do–Check data loop establishes a continuous improvement cycle, manifesting as reduced lead times, enhanced plan fulfilment rates, and steady OEE gains. BAE Systems' end-to-end visualisation and flexible workstations minimise waiting and changeover losses through workstation-level guidance, error-proofing, and dynamic scheduling; cross-system data integration reduces rework caused by information inconsistencies, with improvements released incrementally [7]. Rolls-Royce's digital twins and health monitoring combine high-frequency status data with mechanism/data-driven models to frontload maintenance windows, reduce unplanned downtime, and increase time-on-wing. Benefits manifest in OEE's 'availability' metric and delivery stability; model engineering and data quality emerge as constraints for sustainability [8, 11].

SMEs' improvements follow a 'bottleneck-first, incremental expansion' pathway. A typical sequence involves establishing a visualisation foundation through data collection and kanban boards, followed by deploying small-scale automation and error-proofing at bottleneck locations. Once benefits materialise, process and data governance are retroactively implemented. This sequence can significantly improve (FPYand Lead Time within 3–6 month cycles. OEE improvements gradually emerge when scaling to adjacent processes and adjusting maintenance strategies [5, 6, 9, 10]. Constrained by funding, manpower, and process maturity, improvements often plateau during scaling if governance is absent; external coaching acts as a distinct accelerator in filling methodological and capability gaps [5, 6, 14].

Cross-case mechanism analysis reveals: Visualisation primarily impacts Lead Time and OEE's 'performance' components by reducing search and communication losses, shortening queueing and changeover times; Standardisation enhances FPY and stabilises process capability by reducing rework and quality fluctuations through work instructions, error-proofing, and parameter boundaries; Predictive maintenance improves availability and delivery stability by minimising unplanned downtime via condition monitoring and life models. These three pathways are mutually corroborated across varying scales and process scenarios [10, 11].

Research within a unified metrics framework reveals the organisational and capability mechanisms underlying scale differences. Large enterprises possess the resources and organisational capacity to undertake governance-driven upfront investments, enabling cross-departmental and cross-system interface cleansing and standardisation, subsequently forming a compound improvement curve upon integration. SMEs rapidly pilot initiatives with lower sunk costs, gaining accelerated time and capability gains through external project support [1, 2, 5, 6, 9]. From a dynamic capability perspective, large enterprises exhibit greater complementarity across the three stages of 'perception-capture-reallocation,' particularly excelling in embedding localised technologies into processes and collaborative structures during reallocation. SMEs demonstrate comparative advantages in the speed of perception and capture, though constrained by the governance capabilities and stable resources required for reallocation [12]. Within the TOE framework, technology maturity, organisational resources, and external environments collectively shape adoption decisions. Policy instruments mitigate 'organisational-environmental' constraints through subsidies and guidance, enabling earlier attainment of diffusion thresholds in the 'technology-organisation-environment' alignment [13, 14]. Ethical and sustainability considerations remain paramount. A governance agenda for scaling must concurrently address: data minimisation and purpose transparency; employee monitoring boundaries and participatory governance; algorithmic bias and human verification; alongside the trade-off between edge computing and cloud energy consumption. The primary limitations of this research lie in its reliance on publicly available materials and project evaluations for data sources, lacking uniformly calibrated raw operational data. Consequently, findings are primarily presented as directional evidence. Furthermore, case studies of large enterprises are concentrated in aerospace; future research could enhance generalisability by incorporating examples from general manufacturing and food/assembly industries [7, 8, 10, 11].

5. Conclusion

This paper compares the digitalisation benefit pathways of large enterprises and SMEs within the UK manufacturing sector under a unified framework of Lead Time, FPY and OEE metrics. The large enterprise pathway prioritises governance and integration, yielding delayed yet sustainable benefits with compounding effects; the SME pathway focuses on bottleneck prioritisation and incremental automation, delivering short-cycle results but facing a 'ceiling effect' during scaling due to governance gaps. Policy instruments such as Made Smarter leverage both temporal and capability dimensions, mitigating initial adoption uncertainties while enhancing replication potential through external capability embedding and internal competency development. The managerial implication is to shift digitalisation from a simple 'equipment-software' overlay to a systematic 'data-process' engineering approach, designing implementation pace and sequencing within constraints of scale, process complexity, and organisational maturity. Future research could quantify the marginal contributions of different pathways to OEE components, lead time, and FPY using broader industry samples and stricter data definitions, while assessing the heterogeneous effects of policy tools across regions and supply chain positions.

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