Learning from histories: a systematic review of historical industrial transitions

Ahmad Beltagui[1], Brian Sudlow[2], Miying Yang[3], Qinglan Liu[3], Glen Jonata[3]

[1]Aston Business School, Aston University, Birmingham, UK

[2]School of Social Science & Humanities, Aston University, Birmingham, UK

[3]Group of Sustainability, School of Management, Cranfield University, Cranfield, UK

The transition to sustainability coincides with an industrial digitalization. While this latest industrial revolution creates new challenges, it also revives historical ones encountered in previous transitions. Through two parallel systematic reviews, challenges are identified for the current digitalization transition and historical transitions: mechanization, electrification and computerization. The aim of this research is to identify lessons from history that may help overcome the challenges of industrial digitalization. The paper provides illustrative examples of social factors that are either internal to a technology adopting organization or external, related to wider societal change. These factors suggest actionable insights that may support the adoption of Industrial Digital Technologies.

1. Introduction including aims

Manufacturing industries across the world face two key imperatives: the drive towards sustainability and the transformation led by Industrial Digital Technologies (IDTs). These two may be mutually reinforcing. Digital technologies can enhance resource efficiency, reduce waste and enable circularity [1]. Better forecasting and more responsive production can help to reduce the damaging environmental effects of overproduction and underutilization [2]. Yet adopting digital technologies is fraught with risks and challenges. People are impacted by the technical and organizational changes, while the architecture of a business must be reinvented [3, 4]. And the high degree of real or imagined change creates fear or resistance.

This is not the first time that new technologies have reimagined the industrial landscape, but if IDTs drive a new industrial revolution, what might we learn from past ones? What organizational changes were encountered, how was resistance overcome, and what factors contributed to success or failure? By answering such questions, the aim of this research is to understand ***what challenges may emerge during digitalization, which were encountered in historical industrial transitions?***

History-informed research [5] can support management by developing and testing theory through historical cases (history-to-theory), as this paper sets out to do. Through a Systematic Literature Review (SLR) [6], key themes are identified in the transitions related to mechanization, electrification and computerization, highlighting implications for digitalization.

2. Background

Industrial revolutions are often considered in terms of technological innovations. The steam engine was used to automate many processes, while the computer has dramatically changed the nature of work. At each stage, there has been both optimism and concern about the effect of technology on people. Similar views are evident in current discourse around the fourth industrial revolution. Some see Artificial Intelligence (AI) and Additive Manufacturing (AM) creating clean,

efficient, responsive and responsible manufacturing while others fear automation drives unemployment and deskilling. Both extremes are borne of technological determinism [7], i.e. that technology drives societal change, disruption and revolution.

In contrast, studies in history and sociology of technology have shown a reciprocal relationship between technology and society. From hammers to jet engines to 3D printers [8], the evolution of industrial technologies has been shaped by people's interpretations and uses. Alternatively, theoretical perspectives such as Social Construction of Technology (SCOT) [9], Social Shaping of Technology (SST) and Multi-Level Perspective (MLP) [10] instead look at the sociotechnical interplay that leads to industrial transitions. Previous transitions have evolved management when technologies create new opportunities, but then social factors necessitate new models [11]. For example, mechanization, partly enabled by steam power, created more hierarchical and specialised division of labour, which required balance through worker empowerment. Electrification was accompanied by scientific management, which also necessitated Human Relations in organisations.

Rather than specific technologies or particular time periods, we focus on some of the key industrial transitions [12, 13]. Firstly, the *mechanization* of industries that sees manual activities first automated, secondly *electrification* of industrial processes and a transformation in energy use, thirdly *computerization* and the transformation of knowledge work. By focusing on the sociotechnical interactions involved in these transitions, we aim to uncover the challenges that will be faced during the next transition: d*igitalization*.

3. Research approach

Literature reviews fall on a miner-prospector continuum [14]. Miners deeply examine a bounded and established domain, while prospectors work across disciplinary silos and knowledge boundaries. We adopt the latter approach, drawing on literature from across social sciences to establish a new boundary. We conduct two parallel SLRs, one focused on pre-digital transitions and the other capturing contemporary research related to digitalization.

1. Identification of research: Drawing on prior literature we developed an initial set of search strings related to four key transitions: mechanization, electrification and computerization in one search and separately digitalization in the other. We refer to these as the pre-digital and digital searches.

2. Selection of studies: Search strings were used in academic journal databases (Scopus and Web of Science), the scope of the search was restricted to: Arts and Humanities; Social Sciences; Business and Management; and Economics. A total of 1458 articles was identified for the pre-digital search, and 1371 for the digital search.

3. Study quality assessment: Articles were screened for inclusion. For pre-digital, inclusion was on the basis they reported historical rather than current events and address manufacturing relevant contexts were excluded. E.g. electrification of 20th century agricultural production could be included, while electrification of automobiles in 2020 would be excluded. The total was reduced to 229 articles for review. For digital, inclusion criteria related to the focus on manufacturing and applicability to the UK manufacturing context in particular. Articles were excluded where their focus was overly technical and not offering management implications, or overly theoretical and not offering practical guidance. The total was reduced to 278 articles for review.

4: Data extraction and monitoring: Articles were reviewed independently by at two researchers to identify themes and trends within and across the transitions. Thematic analysis helped to reduce the number of themes in the digital search to 9. These were used as the basis for classifying historical cases. In parallel, the pre-digital search produced additional themes, which are subject to ongoing analysis, and highlight some of the omissions in current research on digitalization.

5/6: Data synthesis and Impact: To make the insights accessible to decision-makers, a set of narrative cases are developed, relating to the identified themes. These present historical decisions that can be related to the challenges and themes of digitalization and can help to inform managerial action.

4. Findings

Our findings relate to the two parallel SLRs. Firstly, the digital review highlighted a set of nine challenges, which could be further categorised under four challenge areas, indicated in table 1. Secondly, the pre-digital search uncovered both analysis and evidence of historical patterns and a collection of in-depth cases with explanatory value. For example, economic analyses offer evidence on how technology has affected work and energy use, while specific cases illuminate the decisions and implications. Table 2 shows some examples.

Digital transition

Analysing the literature on digitalization in manufacturing highlighted a series of challenges related to technologies themselves, but particularly to the social, institutional and organisational factors related to their adoption. However, as figure 1 suggests, the social challenges were less frequently identified in research on digitalization. The most frequently identified challenge was concerned with enabling technology and supporting infrastructure, highlighting the need for digital technologies to be adopted within a context that allows their usage. This can be related to historical examples (table 2) such as the improvement in safety of coal-mining through innovation in supporting technology, or the need for infrastructure to be factored into technology decisions. Next was the challenge around value creation. In a digital context, this often relates to the introduction of data driven technologies, prior to the mechanism for creating and capturing value. In this sense, it may be possible to consider the digital transition as closely related to a business model transition. Historical transitions were accompanied by a change in manufacturing processes, from craft production to mass production to lean production. Similarly, the digital literature suggests a close connection between digitalization and servitization, in which production is led by services. Next on the list in order of frequency are challenges around financing and managing the costs (or benefits) of new technologies. In this area, historical examples also offer valuable examples, for example comparing public and private financing or different approaches to capturing value.

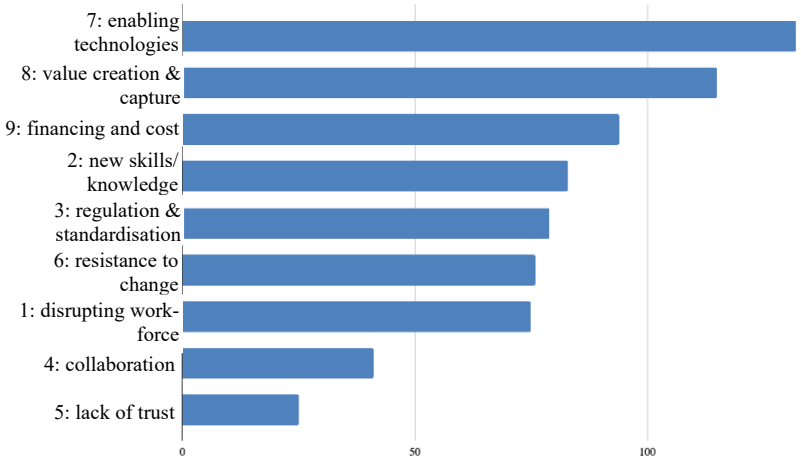

Figure 1 – frequency of identified themes' appearance in digitalization related literature.

Pre-digital transitions

Examining the pre-digital, historical transitions revealed a wide range of disparate cases and topics, but many common themes. As shown in table 2, the challenges identified in digitalization could be used to structure and connect the historical transitions. In this way, insights or examples from mechanization, electrification and computerization could be connected to digitalization, and reveal actionable insights. We sought to classify social factors supporting or preventing successful technology adoption in these historical industrial transitions. These can be divided into external and internal factors.

External factors relate to the wider shifts in policy, business practices, markets and, crucially, in the workforce. For example, much of the literature focuses on the changing nature of work and the need for more skilled and educated workers, along with a more efficient use of energy resources from mechanization to electrification and computerization. More generally, historical evidence and cases help to identify the interplay between individual organisations and the wider environment, for example in relation to collaboration, financing and infrastructure.

Internal factors relate more specifically to how internal operations and organisations have either co-evolved with newly adopted technologies or in some cases prevented such adoption. Some examples suggest technology can help to improve manufacturing or instigate change. Others suggest that organisational and institutional structures can prevent change or limit the extent to which technology adoption can introduce change.

Table 1 – Digitalization challenges identified through the digital SLR

Sub-theme	Digitalization Challenge	Description
A: People and skills	1.Disrupting labour market and workforce requirements	Potential for job-losses as digital technologies automate processes and reduce labour requirement.
	2. Requiring new skills and knowledge for digitalisation	Potential for labour shortages as knowledge and skill requirements are altered by new technologies.
B: Stake-holder collab-oration	3.Standardisation and regulation to enable collaboration	Lack of common regulatory environment and technological standards as basis for collaboration.
	4. Collaboration with external stakeholders	Lack of collaboration due to change of routines, processes and familiarity with technologies.
C: People and technology	5. Lack of trust in technology	People may not trust new technology, or people may not be trustworthy in their use of technology.
	6. Resistance to change	Uncertainty over nature of change and unwillingness to accept new technologies.
D: Costs and benefits	7. Enabling technology and infrastructure	Lack of maturity in infrastructure or supporting technologies restricts technology use.
	8. Value creation and business model	Uncertainty over how to generate value or reduce costs through new technologies.
	9. Implementation costs and financing	High initial investment requirements or uncertainty due to novelty of technologies.

Table 2 – actionable insights and historical examples identified through the pre-digital Systematic Literature Review (references available on request)

Challenge	Historical example	Actionable insight
1: Disruption to labour market (External – workforce change)	Since the 1960s, increasing use of computers has coincided with both job increases, and wage disparity. Analysis shows more demand for skilled workers but also more power and greater rewards for managers.	New technologies replace tasks but not necessarily jobs. Upskilling is likely but training and rewards should be considered.
2: Skills and knowledge (Internal – organisational attitudes and groups)	Typewriters altered the nature of clerical work and contributed to greater employment for women but created negative stereotypes regarding their skills and reinforced barriers to progress.	Technologies create demand for new skills but may be shaped by existing structures and inequalities.
3: Regulation& Standardisation (External – institutional effects on adoption)	The adoption of technologies and mechanization in 18th century Venice was largely influenced by role of guilds that contributed to collective decisions.	Institutional and competitive factors play an important role in technology adoption decisions and should be understood.
4: Collaboration (External – stakeholder engagement)	Analysis of US 1980s data suggests high growth cities associated with a focus on innovation and services, with collaboration enabled by communications technology.	Technology can enable communication and decentralisation, with benefits where collaboration is pursued.
5: Trust (Internal – behaviour and agency)	New York Stock Exchange introduced a computerized replacement for the famous ticker tape system to reduce errors and inefficiency. While this reduced some fraud, it also allowed malpractice at the data input stage.	When technology is introduced to 'fix' problems, the unintended consequences and impacts on people must also be considered.
6: Resistance to change (Internal – stakeholder engagement)	Bilhai Steel Plant in India faced resistance to planned automation that would have led to job losses. By involving employees in introducing semi-mechanized processes, new improvements were unexpectedly identified.	Involvement of affected stakeholders (including employees) can improve the results of technology adoption.
Challenge	**Historical example**	**Actionable insight**
7: Technologies and infrastructure (External – stakeholder engagement)	Zurich in Switzerland faced a choice of power for street lighting, but no option was superior on technical grounds. Considering political factors and growth plans led to AC power being chosen for scalability.	The right choice among competing technologies may be based on non-technical factors rather than technological superiority.
8: Generating value (Internal – operations and change)	Factories improved their productivity through electrification. This was in part explained by indirect benefits such as removing constraint of shafts powered by steam when introducing electrical wires and	New technologies can create efficiency improvements, but realising benefits requires assumptions to be reconsidered.

	more flexible layouts.	
9: Financing and costs (External – local/global and public/private trade-offs)	Spain and Argentina underwent electrification post WW2. Argentina relied on foreign investment and control, Spain more local. Argentina's electrification was more profitable but less equitable.	Considering transition may require a broad perspective on investment and the nature of returns.

5. Implications for digitalization

The research seeks to identify challenges that have faced technology adopters in the past, which can inform decisions in the future. Specifically, we began with the assumption that the social factors affecting digitalization will be similar to those encountered during previous industrial transitions. Our review of literature suggests that contemporary studies focus on the technological challenges of digitalization but may not capture all of the social ones. Similarly, literature on historical revolutions has been criticized for an overemphasis on technology.

Examining historical accounts underlines the importance of the context in understanding industrial transitions, where surrounding social factors along with technological factors form a seamless web [15]. The SLR incorporates long term economic analyses that identify changes in these social factors. For example evidence of more efficient energy use, changing nature of employment and increasing skill level in jobs over decades. The review also captures in-depth qualitative accounts, which uncover the social contexts and explanations for these changes to be considered. As a result, our findings suggest that, despite differences in the technologies, there is much to learn from the decisions and outcomes of the past. In particular, the unintended consequences, whether these were serendipitous improvement opportunities or unexpected barriers, are experienced repeatedly.

There is often a temptation to focus on the potential of new technologies, and this is particularly true of IDTs. Expectations attributed to robotics and AI might be compared with those related to typewriters or automobiles in the past. Historical evidence suggests both of these technologies did change people's lives for the better, but also that new problems related to gendered workplaces or air quality emerged. By considering such historical cases, it may be possible to have more realistic expectations and better predict the challenges in a given context.

The main limitations of this work relate to the breadth and consequent lack of depth of analysis in a SLR. Further work is required to develop the analysis further. From a theoretical perspective, ongoing examination seeks to build an explanatory framework that captures the key challenges and success factors of industrial transitions. In particular, such a framework must be tested to ensure it gives meaningful insight into contemporary challenges. For practice, in order to create actionable insights, the next steps are to package the findings into an accessible form and to explore the degree to which past solutions may apply to present problems, to help identify future ones.

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