Enabling distributed manufacturing through digital skills development

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Abstract
Distributed manufacturing seeks to improve accessibility, transparency, and inclusivity within manufacturing supply chains, benefiting all stakeholders, including suppliers, customers, and broader communities. However, there exists a significant gap in understanding the involvement of these stakeholders in enabling distributed manufacturing and its integration into the manufacturing value chain to address societal issues such as skills, employment, and inclusivity sustainably. To remain competitive, the manufacturing supply chain sector must embrace digital technologies. However, the digital skills gap in manufacturing highlights a disparity in digital competencies among workers and businesses, hindering the integration of critical technologies such as data analytics, visualisation, automation, and artificial intelligence. Surveying 135 UK manufacturing and engineering businesses revealed shortages in skills related to business analytics, web/app development, and artificial intelligence/machine learning/augmented reality (AI/ML/AR), robotics, and systems integration. Looking ahead, digital technologies such as additive manufacturing, AI/ML/AR, and robotics/process automation are perceived as vital skill sets for the UK economy in the next five years. This research aims to shed light on the current digital skill requirements in the manufacturing supply chain, explore anticipated future digital skill needs, and identify optimal approaches for enhancing digital skills in the future.

Keywords: Distributed manufacturing, digital skills, collaboration and co-creation

Introduction

The manufacturing supply chain sector is undergoing a digital revolution. Manufacturers need to adopt digital technologies to remain competitive but face severe skills shortages. The challenge of attracting people to highly skilled manufacturing jobs is due in part to a lack of understanding and interest in the opportunities in modern manufacturing and engineering. The manufacturing digital skill divide displays a disparity in digital competencies among workers and businesses, impeding the integration of crucial technologies like automation and artificial intelligence, etc. (Mahoney and Pilditch, 2017).

Distributed manufacturing is about making manufacturing supply chains more accessible, transparent, and inclusive for all stakeholders, including suppliers, customers, and wider communities. The key characteristics of such democratised and distributed supply chains are consumer and community involvement in value co-creation, adoption of digital technologies, diffusion of technology, and novel governance structures and business models. Within the context of supply chains, researchers have suggested major interventions to include disintermediation, the use of distributed manufacturing (Srai et al., 2020; Rayna et al., 2015).

This research will contribute to knowledge on enabling the process of a distributed manufacturing network with multiple stakeholders and how that network can best be supported with specific objectives in terms of digital skills development to bridge the manufacturing and supply chain digital skill divide. It contributes valuable insights to the enabling of a distributed manufacturing network, emphasizing skills development and facilitating local manufacturers' access to a proficient workforce. The research underscores the importance of collaborative efforts in overcoming the digital skill divide within the manufacturing and supply chain sector in the UK.

A further challenge to manufacturers may stem from insufficient awareness and interest in modern manufacturing, leading to challenges in attracting skilled talent. Addressing this issue requires community involvement, awareness-building, and collaboration initiatives. Surveying 135 UK manufacturing and engineering businesses, this project aims to understand challenges faced by local manufacturers in upskilling employees amid digital transformation and attracting future talent in the UK.

Brief Literature Review

The manufacturing supply chain sector is currently experiencing a digital transformation. In order to stay competitive, companies must embrace digital technologies, yet they are grappling with significant skill shortages. The difficulty in attracting talent to high-skill manufacturing positions stems from a lack of awareness and interest in the opportunities available in modern manufacturing and engineering. This digital skills gap within manufacturing highlights a disparity in digital capabilities among both workers and businesses, hindering the seamless integration of vital technologies such as automation and artificial intelligence (Mahoney and Pilditch, 2017).

Distributed manufacturing can be defined as: "technologies, systems, and strategies that alter the economic and organisational dynamics of manufacturing, particularly in terms of location and scale" (Durach et al., 2017). The phenomenon pertains to a growing shift from global (offshored) to more localised (near-shored) manufacturing, as well as a departure from large, centralised production toward smaller, decentralised (distributed) operations (Purvis et al., 2021). A study implies that distributed manufacturing , with its utilization of new technologies, has the potential to disrupt conventional supply chains and represents a novel localised mode of production (Laplume et al., 2016). In contrast to the industrial paradigm built on economies of scale, distributed manufacturing could evolve into a business model centered around economies of scope (Srai et al., 2016).

A co-evolutionary approach to distributed manufacturing is prevalent in the literature. This perspective, explored by Dekkers (2010), underscores the dynamic collaboration and communication within networks. Dekkers sheds light on the relationship between distributed manufacturing and co-evolution. Co-evolutionary frameworks take into account autonomous agent development, fitness landscapes (such as the NK model), percolation, and symbiosis. Co-evolution refers to the mutual adaptation and development of interconnected entities within a system. In the context of industrial networks, co-evolution occurs when various actors (such as manufacturers, suppliers, and consumers) adapt and evolve together. Challenges faced by contemporary industrial networks include collaboration, decentralisation of decision-making, and interorganizational integration. Fitness landscapes represent the possible states or configurations of a system and consider the connected traits of agents. They capture how changes in one trait affect the fitness of the entire system. However, real-world industrial

landscapes are dynamic, unlike the semi-static assumption of the NK model. Percolation theory examines how components connect within a network, helping to understand the emergence of critical structures. Symbiosis refers to mutually beneficial interactions between different entities. In industrial networks, symbiotic relationships can lead to innovation and resilience. Distributed manufacturing aligns with emerging priorities like agility and customisation, with collaborative networks playing a pivotal role. Game theories could provide insights into collaborative behaviors within distributed manufacturing networks. In summary, a co-evolutionary approach recognizes the interplay between agents, their adaptation, and the dynamic nature of distributed manufacturing networks, providing valuable insights for designing resilient and innovative manufacturing systems (Dekkers, 2010).

Distributed manufacturing aims to enhance accessibility, transparency, and inclusivity within manufacturing supply chains, benefiting all stakeholders including suppliers, customers, and broader communities. These decentralised supply chains are characterised by active involvement from consumers and communities in value co-creation, the integration of digital technologies, widespread diffusion of technology, and the implementation of innovative governance structures and business models. Within the realm of supply chain management, researchers advocate for significant interventions such as disintermediation and the utilization of distributed manufacturing practices. It facilitates shorter lead times and lowers the risk of obsolescence, enabling agile responses at reduced overall supply chain costs. However, it could also result in more intricate supply chains, characterised by a greater number of smaller, adaptable production systems distributed globally (Purvis et al., 2021).

Enabling distributed manufacturing to bridge digital skills gaps needs the active participation of consumers and communities in value co-creation, adoption and diffusion of digital technologies, and the implementation of novel governance structures and business models. In the realm of supply chain management, researchers advocate for significant interventions such as disintermediation and the adoption of distributed manufacturing practices (Srai et al., 2020; Rayna et al., 2015).

In this context, co-creation stimulates innovation and addresses diverse customer needs in a distributed manufacturing context. It differs from co-design, which concentrates solely on the collaborative design process. Co-creation entails the collaborative creation of value among multiple parties, transcending conventional customer-supplier dynamics. While customers frequently participate in co-creating products or services, other stakeholders, including suppliers, employees, and regulators, can also engage in this collaborative process. In the realm of distributed manufacturing , co-creation manifests in various ways:

- Customers: Offering insights on features, functionality, and customisation options via online platforms or communities.
- Consumer Co-Creation: Consumers actively participate in product design, features, or content. For instance, open-source hardware projects involve collaborative design and development by a community of enthusiasts.
- Designers: Translating customer ideas into technical specifications while integrating expertise in materials and manufacturing processes.
- Manufacturers: Geographically dispersed, they utilise their specialised capabilities to produce various parts of the product.
- Integration of Product Design and Manufacturing: Co-creation takes place when product design and manufacturing processes are closely intertwined. This integration enables quicker iterations and customisation.

- IP-Driven Lock-In Partnerships: Certain distributed manufacturing models entail partnerships centered on intellectual property (IP) sharing. These partnerships facilitate collaborative innovation and value generation (Srai et al., 2020).

Methodology

A questionnaire designed to focus on current digital skill needs, the perception of future digital skill needs and the best ways in which future digital skills could be improved, was adminstered to a sample of manufacturers, engineering companies and logistics firms in the Midlands of the UK. Respondents were asked their perceptions of whether the digital skills in their organisation were below their current needs, met their current needs, or were at a specialist level. Respondents were also asked their perceptions of which digital skills would be the most critical for their organisation in the next five years and also for the wider UK in the next five years. Furthermore, espondents were asked which methods they would find most useful to support digital upskilling.

Current digital skills

Respondents were asked their perceptions of whether the digital skills in their organisation were below their current needs, met their current needs, or were at a specialist level. The skills were divided into 9 categories:

- Office/administrative skills, covering general office tasks (e.g. MS Word, MS Excel, email, social media, video meetings)
- Business application skills, e.g., online purchasing/sales, digital marketing and content creation)
- Business analytics and data visualisation
- Web or app development
- Digital design (e.g. CAD, CAM)
- Additive manufacturing (e.g., 3D printing)
- Artificial intelligence/machine learning/augmented reality (AI/ML/AR)
- Robotics and process automation
- Systems integration (e.g. MRP and inventory management)

Future digital skills

Respondents were also asked their perceptions of which digital skills would be the most critical for their organisation in the next five years and also for the wider UK in the next five years. The digital technology skills surveyed were:

- Artificial intelligence/machine learning/augmented reality
- Robotics and process automation
- Business analytics
- Digital marketing and content creation
- Systems integration (e.g. MRP and inventory management)
- Web or app development
- Data visualisation
- Additive manufacturing (e.g., 3D printing)
- Digital design

Methods to improve digital skills

Respondents were asked which methods they would find most useful to support digital upskilling:

- Online training for individuals
- Face to face training in schools/colleges/workplaces
- Embedding digital technologies within the curriculum for secondary school and professional education.
- Regular sessions by technology ambassadors from industries as part of school education.
- Online training for groups
- Community level facilities where people can learn and practice with digital technologies for real-world applications.
- A digital platform connecting manufacturers, digital technology service providers, educational institutions.

Not all respondents answered all questions, hence there are slight variances in responses across the different sections.

Sample

A questionnaire was sent to a wide range of organisations across the Midlands of the UK, resulting in 135 respondents from engineering, manufacturing, and logistics firms, across a wide range of firm sizes (based on number of employees). 81.5% of respondents were located in out-of-city locations (typically small towns) and 96% of respondents were small and medium-sized enterprises (SMEs), which is close to the UK-wide demographic, where SMEs represent 99.05% of UK businesses (Barton, 2023)(UK Government, 2023). The summary data of the sample is demonstrated in Tables 1 and 2.

Table 1 Sample summary data (number of respondents)

	Size									
Industry	Micro		Small		Medium		Large		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Engineering	10	25.0%	15	37.5%	14	35.0%	1	2.5%	40	29.6%
Logistics	2	16.7%	4	33.3%	4	33.3%	2	16.7%	12	8.9%
Manufacturing	22	26.5%	32	38.6%	26	31.3%	3	3.6%	83	61.5%
Totals	34	25.2%	51	37.8%	44	32.6%	6	4.4%	135	100.0%

Table 2 Sample summary (by location)

Industry	Location				
	City		Non-city		Total
Engineering	8	20.0%	32	80.0%	40
Logistics	3	25.0%	9	75.0%	12
Manufacturing	14	16.9%	69	83.1%	83
Totals	25	18.5%	110	81.5%	135

Results

Current skills levels

The survey results revealed that unsurprisngly at the less technical skill levels, such as general office and business applications, the majority of respondents were satisfied with their current skill levels.

Table 3 Summary of current skill needs assessment (all respondents)

Current needs assessment	General office	Business application	Business analytics	Web or app development	Digital design	Additive manufacturing	AI/ML/AR	Robotics & process automation	Systems integration
Below	8.1%	8.9%	32.6%	25.2%	11.1%	11.9%	23.7%	22.2%	26.7%
Sufficient	82.2%	79.3%	48.1%	43.0%	45.2%	24.4%	16.3%	18.5%	37.8%
Specialist	9.6%	11.1%	7.4%	6.7%	20.7%	3.0%	0.7%	2.2%	6.7%
N/A	0.0%	0.7%	11.9%	25.2%	23.0%	60.7%	59.3%	57.0%	28.9%

However, there was a notable recognition of skills shortages in business analytics and web/app development and for AI/MR/AR, robotics and systems integraton skills, despite more companies not having needs of such specialist skills. Table 3 shows where the large gaps are, which is further highlighted in figure 1.

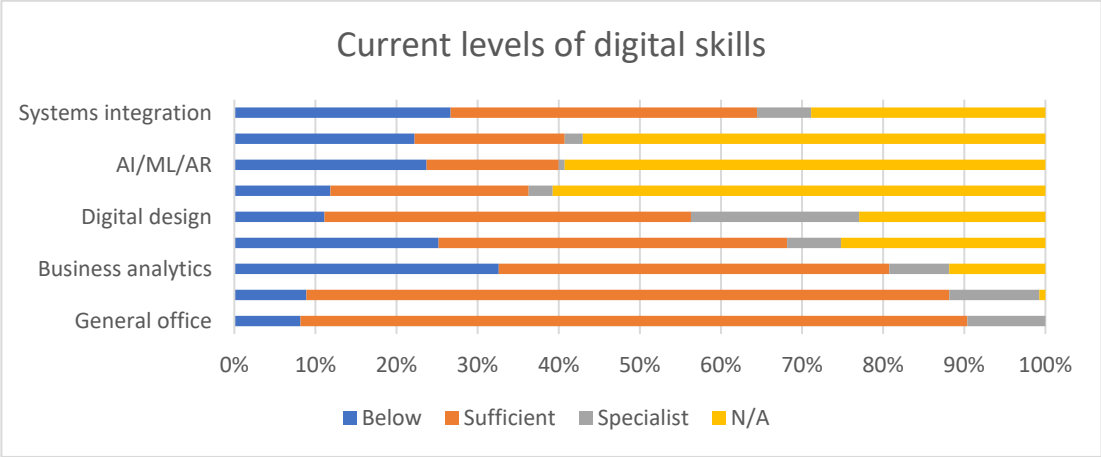

Figure 1 Current digital skills assessment by topic, normalised to 100%

Future skills assessment

When looking ahead to the future, respondents had differing views about their own organizations' needs versus their perceptions of what the UK as a country needs. Figure 2 below shows that in their own organizations, respondents have strong needs in systems integration, business analytics, web or app development and digital marketing, seeing these as a way to make their own organizations more efficient and maintain vital connections with their customers and market. Clearly, this is a very specific internally driven need to reduce costs and remain competitive into the future.

More specialist technologies such as additive manufacturing, AI/ML/AR and robotics/process automation were less likely to be needed by an individual organization, however, respondents perceived these skillsets as being vital to the UK economy in the next five years.

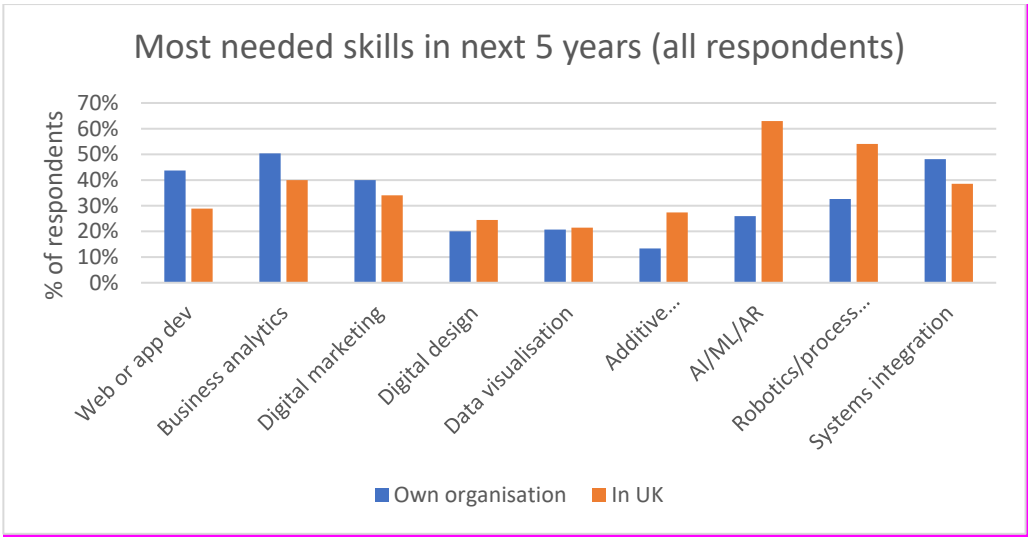

Figure 2 Most needed skills in the next five years (own organization and UK)

At industry level, engineering companies were most likely to consider business analytics and data visualisation as key skills for the next five years (18.6% of respondents), followed by systems integration (15.7%), digital marketing (15.7%) and web/app development (11.8%) as noted in Table 4. Logistics firms see AI/ML/AR (17.9%), systems integration (14.3%), business analytics (14.3%) and robotics and process automation and web/app development (both 10.7% of respondents) as the top skills needed in their organizations in the next five years. Manufacturing organizations were also largely focused on systems integration (18.1%), digital marketing (14.5%), robotics (14.1%) and business analytics (14.1%) as their main digital skill requirements in the short to medium-term.

Table 4 Top skills needed in organisations in next five years

Needed in own organisation	Web or app development	Business analytics	Digital marketing	Digital design	Data visualisation	Additive manufacturing	AI/ML/AR	Robotics & process automation	Systems integration
Engineering	11.8%	18.6%	15.7%	11.8%	7.8%	3.9%	8.8%	5.9%	15.7%
Logistics	10.7%	14.3%	7.1%	7.1%	14.3%	3.6%	17.9%	10.7%	14.3%
Manufacturing	13.7%	14.1%	14.5%	5.2%	6.8%	5.2%	8.4%	14.1%	18.1%

Organizations' perceptions of the digital skills needed in the UK in the next five years differ from their own organizational requirements. Table 5 shows how despite not needing AI/ML/AR in their own organizations, 15.6% manufacturers and 22.6% of engineering companies regarding it as one of the top digital skills needed nationally in the short and medium-term. Equally, robotics and process automation are seen as key digital skills needed in the UK by all three industry groups, and business analytics and data visualisation still being needed nationally, as can be seen in Table 5.

Table 5 Top skills needed in the UK in the next five years

Needed in the UK	Web or app development	Business analytics	Digital marketing	Digital design	Data visualisation	Additive manufacturing	AI/ML/AR	Robotics & process automation	Systems integration
Engineering	7.5%	12.0%	12.8%	6.0%	7.5%	7.5%	22.6%	14.3%	9.8%
Logistics	6.3%	6.3%	6.3%	9.4%	3.1%	9.4%	28.1%	21.9%	9.4%
Manufacturing	9.2%	11.6%	9.9%	7.5%	6.5%	11.6%	15.6%	16.0%	12.2%

Methods to improve digital skills

The sample was asked to evaluate the best ways they believed would improve digital skills through a range of activities, as noted in Table 6. The trend appears to be away from individual learning to more collaborative forms of learning, usually online, as opposed to face-to-face. Integrating skills into curricula (96.2% of respondents finding this method quite or very useful), connecting through digital platforms or online (both 95.4%), and with communities (95.3%) and were seen as the most impactful when developing digital skills. This suggests that collaborating solutions digitally within groups, rather than at individual level may enhance digital skills in industry and the wider community.

Respondents	Response	Face to face training	Online training (individuals)	Online training (groups)	Digital platform connection	Community facilities	Curriculum integration	Industry sessions
All respondents	Not useful	5.3%	5.3%	4.6%	4.6%	4.7%	3.8%	5.3%
	Quite useful	42.0%	49.6%	39.2%	38.9%	39.5%	41.5%	51.5%
	Very useful	52.7%	45.0%	56.2%	56.5%	55.8%	54.6%	43.2%

Discussion and Conclusion

Fostering distributed manufacturing through the enhancement of digital skills is paramount for cultivating resilience and elevating productivity within the manufacturing sector. Adaptability and agility play vital roles in achieving distributed manufacturing. Also, the manufacturing industry needs to establish comprehensive digital skills training programs for their employees. Furthermore, these should cover a wide range of digital skills, including data analytics, cybersecurity, automation, and virtual collaboration tools which should accelerate. Finally, there should be encouragement for lifelong learning by providing ongoing training opportunities (Make UK, 2020; WEF, 2020).

In our study, which surveyed 135 UK manufacturing and engineering businesses, we uncovered deficits in skills associated with business analytics, web/app development, and artificial intelligence/machine learning/augmented reality (AI/ML/AR), as well as robotics and systems integration. Looking forward, digital technologies such as additive manufacturing, AI/ML/AR, and robotics/process automation are regarded as crucial skill sets for the UK economy in the next five years.

At the industry level, engineering companies prioritize business analytics and data visualisation as key skills for the next five years, with 18.6% of respondents highlighting this need. Following closely are systems integration (15.7%), digital marketing (15.7%), and web/app development (11.8%), as indicated in Table 4. Logistics firms identify AI/ML/AR (17.9%), systems integration (14.3%), business analytics (14.3%), and robotics and process automation, along with web/app development (both noted by 10.7% of respondents), as the top skills required in their organizations over the next five years. Similarly, manufacturing organizations predominantly focus on skills like systems integration (18.1%), digital marketing (14.5%), robotics (14.1%), and business analytics (14.1%) as their primary digital skill requirements in the short to medium term.

The results of the study confirmed that active participation and co-creation of the wider community which includes technology service providers, educational institutions, local authorities is essential to address digital skills gaps and enable distributed manufacturing. This participation entails the adoption and diffusion of digital technologies, along with the implementation of novel governance structures and business models.

Co-creation plays a pivotal role in driving innovation and meeting diverse customer needs within a distributed manufacturing context. Unlike co-design, which concentrates solely on collaborative design, co-creation involves multiple stakeholders collaboratively creating value, transcending traditional customer-supplier relationships. While customers commonly contribute to co-creating products or services, other stakeholders such as suppliers, employees, and regulators can also engage in this collaborative effort (Srai, 2020).

In summary, distributed manufacturing aims to enhance accessibility, transparency, and inclusivity within manufacturing supply chains, thereby benefiting all stakeholders, including suppliers, customers, and broader communities. There is limited understanding of how all stakeholders, including suppliers, customers, and wider communities, can be involved in the co-creation of manufacturing value chain and how this can sustainably address societal issues of skills, employment and inclusivity. The manufacturing supply chain sector needs to adopt digital technologies to remain competitive. The manufacturing digital skill divide signifies a disparity in digital competencies among workers and businesses, impeding the integration of crucial technologies like data analytics and visualisation, automation, and artificial intelligence, etc. To address these issues, this research sheds light on current digital skill needs in the manufacturing supply chain, explores the anticipation of future digital skill needs and identifies the best approaches for enhancing future digital skills. Indeed, the intersection of distributed manufacturing supply chains and co-creation is significant, with co-creation playing a vital role in shaping the future of localised and collaborative manufacturing.

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