In partnership

Skills needed for the safe adoption of emerging technologies in engineering

Full report

The RSA

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Acknowledgments

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i About us

We are the RSA. The royal societyfor arts, manufactures and commerce. Where world-leading ideas are turned into world-changing actions. We're committed to a world where everyone can fulfil their potential and contribute to more resilient, rebalanced, and regenerative futures.

The RSA has been at the forefront of significant social impact for over 260 years. Our research and innovation work has changed the hearts and minds of generations of people. Central to all our work are our mission-aligned Fellows; a global network of innovators and changemakers who work collectively to enable people, places and the planet to flourish in harmony.

We invite you to be part of this change. Join our community. Together, we'll unite people and ideas in collective action to unlock opportunities to regenerate our world. **Find out more at thersa.org**

We define our ambitions as:

Our mission

To enable people, places and the planet to flourish in harmony.

Our vision

A world where everyone can fulfil their potential and contribute to more resilient, rebalanced and regenerative futures.

How we deliver our work

We do this by uniting people and ideas in collective action to unlock opportunities to regenerate our world.

About our partner

Lloyd's Register Foundation is an independent global charity that supports research, innovation, and education to make the world a safer place. Its mission is to use the best evidence and insight to help the global community focus on tackling the world's most pressing safety and risk challenges. For more information, please visit www.lrfoundation.org.uk

ii Foreword

Lloyd's Register has been at the frontier of technological innovation since it was founded in 1760, including playing a major role during two energy transitions as the maritime industry shifted from wind to coal, and coal to diesel.

It's our long-standing credibility in this space that led Lloyd's Register Foundation to investigate current emerging technologies in engineering, such as robotics, automation and the Internet of Things, and what skills will be required to ensure they are adopted safely.

Generation-defining safety challenges are giving us an urgent incentive to adopt emerging technologies – to improve failing infrastructure, protect workers from harm, and of course, decarbonise to save the planet.

However, without building capacity in developing nations to ensure the next generation of engineers have the right skills to safely use new technologies, we won't be able to mitigate these threats to society, and risk endangering the safety of billions of people around the world.

This report, in collaboration with the RSA (the royal society for arts, manufactures and commerce), provides real, actionable insights into how the international community can resolve skills shortages in the global engineering sector. The recommendations provide guidance that is sustainable, and will allow key industry stakeholders to produce effective interventions that will ensure engineering skills and education can support technological innovation.

I'm extremely proud of Lloyd's Register Foundation's involvement in making this report happen, and confident it will prove a valuable asset to organisations that share our mission of making the world a safer place.

Tim Slingsby, director of skills and education, Lloyd's Register Foundation

Executive summary

This report aims to identify the skills needed for the future of engineering and safe adoption of emerging technologies. It also explores how actors in the engineering skills system can work together to ensure that a diverse range of learners and workers are able to develop these skills and thrive in the future of work.

The world of engineering is undergoing considerable transformation, subject to changing demographics and with an increasingly global, competitive workforce, alongside seismic technological changes. These emerging forms of technology present both opportunities and challenges with regards to worker safety, environmental safety, and cyber security. To respond effectively to these changes, the engineering sector needs a workforce trained not just in emerging technologies but also in how to adopt them safely.

Future skills

Skills category	Summary of new skills needed for the safe adoption of emerging technologies
Technical: skills relating directly to specialist engineering knowledge and capabilities.	• Interdisciplinary approaches to work, especially among team leaders • Cross-cutting knowledge of programming languages • Specialist knowledge and tools relating to data analysis and data management • Specialist technical knowledge relating to specific forms of technology • Specific design skills such as computation geometry and circuit design
Digital: skills relating to digital knowledge and capabilities.	• Knowledge of specific programming languages and proprietary languages • Design skills requiring specialist knowledge of digital tools • Machine learning (ML) and deep learning (DL) skills to ensure safety and security
Safety: skills relating directly to safety knowledge and capabilities.	• Safety requirements will be closely linked to digital skills (above) • Competency in real-world testing and experimentation, including 'ethical hacking' to stress-test vulnerabilities • The ability to conduct risk assessments and skills in risk management, as well as more specialist knowledge in relation to specific technologies • Knowledge of how to safely intervene in human-machine interactions • Specialist knowledge with regards to regulatory compliance, certification and documentation processes
Transferable: general skills that could be adapted to other professional contexts, engineering or otherwise.	• Systems thinking, analysis and evaluation to integrate new technologies into the industry • Entrepreneurial skills to spot value-adding opportunities • Knowledge of and ability to anticipate sustainability and safety implications • A continued (and currently under-served) need for practical skills (such as assembly, welding and soldering)

Recommendations

Foundational skills and mindsets – for policymakers, schools and colleges:

- Safety-related components of the digital, technical and transferable skills learnt in school should be embedded in school curricula.
- Greater efforts are required to build the pipeline of computing teachers, as well as drawing on capacity and expertise within the technology sector to ensure up to date pedagogy and content.
- School pupils should be exposed to not only a broader range of disciplines for longer, but also to the practice of combining multiple disciplines.
- There should be greater investment in transferable 'meta-skills'.

Further, higher and professional training – for further and higher education providers, local and national policymakers:

- Professional training should embrace agile and lifelong forms of learning, including skills passports and digital badging, and skills bootcamps.
- Ensure improved access to upskilling opportunities, especially among underrepresented groups.

Organisational culture, support and opportunities – for employers and the sector:

- Responsibility for safety skills development should rest at an organisational level, recognising the role of culture in determining safety behaviours and incentivising in-house development of skills.
- Improve incentives for safety training, for example by making it more accessible and desirable to individuals and organisations. Incentives also need to be strengthened through the role of regulators and continuing professional development (CPD) requirements to maintain registration.
- Build learning and organisational cultures which are open to challenge and agile to change.

INTRODUCTION

Introduction

Purpose

This report aims to identify the skills needed for the future of engineering and safe adoption of emerging technologies. It also explores how actors in the engineering skills system can work together to ensure that a diverse range of learners and workers are able to develop these skills and thrive in the future of work.

The primary audience we hope to reach with this report includes business leaders, HR and learning and development professionals in the engineering sectors, as well as learning providers and policymakers in the skills system. As well as engineering professionals, this report may be of value to students and individuals with an interest in becoming engineers or exploring what skills might become increasingly relevant in the future.

We have worked iteratively and systematically to understand the current and changing world of engineering, the evolving impacts and uses of emerging technologies, the skills needed to safely adopt these in a changing world and sector, and ways to strengthen and embed these across the sector.

Scope

Engineering is an expansive field and a flexible term with no exhaustive definition. The Cambridge dictionary defines engineering as **"the study of using scientific principles to design and build machines, structures, and other things, including bridges, roads, vehicles, and buildings".**[2.]

Given the report's focus on skills and roles, **the most useful classification we have identified is EngineeringUK's 'engineering footprint'** – "a means of creating a working definition of engineering by classifying which jobs and industries count as 'engineering'" – developed in partnership with the Royal Academy of Engineering (RAEng) and the Engineering Council. The **key feature of this definition is that it defines engineering functionally in terms of engineering jobs that require the consistent application of engineering knowledge and skills to execute the role effectively**, and related jobs, rather than attempting an exhaustive definition.[3.]

Workers in engineering sectors such as manufacturing and construction also **include tradespeople, mechanics, metal workers and process operatives.** All these roles are important in ensuring safety and security, but these workers have different skills, qualifications and educational backgrounds, meaning that the adoption of emerging technologies will impact differentially.

The **scope of safety in this report will cover both the safety of work** (ie reducing worker health and safety risks) **and safety work** (ie safety engineering). We also explore the skills needed to manage **adjacent risks relating to cyber security and environmental impacts** of emerging technologies.

2 Cambridge Dictionary (nd) Engineering [online] Available at: www.dictionary.cambridge.org/dictionary/english/engineering [Accessed 2023].
3 Morgan, R (2018) Defining the engineering sector: the engineering footprint. [PDF] Engineering Council. Available at: www.partner.engc.org.uk/media/9134/engineering-footprint-report-summary-raeng.pdf

Structure

Each chapter begins with a summary of its key themes and findings, with greater discursive detail outlined thereafter. The structure of the report reflects the iterative approach we have taken to this research.

Chapter 1 explores how the world of engineering is changing. The chapter looks at how broad demographic and technological trends – such as digitisation, automation and decarbonisation – are impacting engineering the sector and jobs globally. *This chapter brings together insights from research summaries of global trends in engineering and a horizon scan of emerging technologies.*

Chapter 2 reviews the current landscape of engineering skills. This chapter begins by flagging evidence and data on key skills shortages in engineering. We go on to identify and categorise the most pertinent skills relevant to engineering under the headings of technical, digital, safety, and transferrable skills. Where appropriate we also use findings from our analysis of European Skills, Competences, Qualifications and Occupations (ESCO) to illustrate the extent to which these skills are unique or transferrable to different occupations, and their susceptibility to automation. *This chapter summarises insights from a landscape review drawing on the relevant literature, and the RSA's analysis of ESCO skills-occupation data.*

Chapter 3 explores safety challenges and opportunities offered by emerging technologies, and the skills needed for their safe adoption. The first half of this chapter reflects on how three exemplar emerging technologies – the Internet of Things, robotics and automation, and hydrogen – are being adopted in different engineering contexts and sectors, and discuss common safety challenges and opportunities associated with each.

We then reflect on the different technical, digital, safety and transferrable skills that could be needed to safely adopt these emerging technologies. The result is a skills framework that both consolidates existing best practice and offers additional insight in how this might be futureproofed. *This chapter brings together insights from our review of the skills landscape and our horizon scan of emerging technologies.*

Chapter 4 presents recommendations for how engineering workers and their employers can be supported to implement these learnings in practice. We consider examples of innovative and effective practice in the form of case studies, and advance a series of recommendations to embed relevant skills and cultures across the engineering landscape to support the safe adoption of emerging technologies. *This chapter reflects the findings of previous chapters, and a series of workshops with industry professionals to co-create proposed solutions.*

Methodology

This research project has drawn on a range of sources and methods to advance a meaningful, valuable and practical skills framework for the safe adoption of emerging technologies. These include:

- **Secondary analysis of UK employment data** to support the development of the skills framework and explore how engineering occupations and industries benchmark against indicators of employment change due to digitisation, automation, and decarbonisation. (Greater methodological detail and interpretative guidance are provided alongside these findings in Section 2.3).
- An **original quantitative analysis of ESCO skills data** to help develop the skills framework by situating it in a broad understanding of current and future engineering skills demands.
- A scan of the **global engineering context** and the impacts of long-term trends.
- A **literature review** focused on defining engineering skills in **current skills frameworks**. (While the scope of this review was global, it should be noted that the majority of relevant skills frameworks were sourced from Europe, North America and Oceania).
- A **horizon scan** exploring how exemplar emerging technologies are being adopted across the engineering sector, and identifying associated **safety challenges and opportunities**, and **relevant skills demands.**
- Semi-structured **qualitative interviews/workshops with sector experts** to augment our emerging technology framework with expert qualitative insight.
- **Focus groups to stress-test** and iterate our findings.
- A **desk-based global best practice review**, which explores the leading best practice skills and training examples from around the world relating to the adoption of new technologies in engineering and other sectors.
- A series of **workshops with industry experts**, supported to diagnose systemic challenges, before co-producing news solutions to those challenges.
- A **deep dive**, conducted by researchers from the University of York, into the **literature on the safety activities that developers of systems must pay attention to** with respect to the implications on new technologies in their domains and the potential associated training and education needs that emerge. (This can be found in Appendix 5).

These diverse methods generated a large bank of data. Different methods and insights were written up in specific chapters but informed the discussion throughout the report. Figure 0.1 on the next page summarises which research methods were employed for each chapter and research topic.

Further methodological detail on the horizon scan, literature review, and quantitative analysis is also provided in the Appendix, and interpretative guidance pertaining to our analysis of the ESCO skills data is provided (in context) in Chapter 2.

Figure 0.1: Summary of methodologies used to address given research topics/questions

Chapter:	1	2		3			4	Overall/ misc
Research theme / question:	Trends in engineering	Automation risk profiles	Current skills needs and gaps	Uses / applications of emerging technologies	Emerging skills needs	Emerging good practice	Recommendations	Stress-test and contextualise findings
Analysis of employment data	■	■	■					
Global engineering context scan	■							
Analysis of ESCO skills data		■	■					
Literature review	■		■			■		
Horizon scan	■			■	■			
Workshops with industry experts				■	■	■	■	
Focus groups						■	■	■

CHAPTER 1: TRENDS IN ENGINEER-ING

1

Trends in engineering

This chapter explores **how emerging technologies are impacting engineering**. The chapter begins by framing the overall current state of the engineering landscape in light of **key demographic and employment-related trends.** It then looks in depth at **how broad technological trends** such as digitisation, automation and decarbonisation are **impacting engineering jobs globally** and offers insights into exemplar emerging technologies, considering how the **Internet of Things, robotics and autonomous systems and hydrogen** are being adopted in different engineering contexts.

1.1 Demographic patterns and trends

This section explores the impacts of demographic changes on engineering. We find that:

Key points

- **Engineering constitutes a significant and growing share of employment in the UK.**
- **Following broader demographics, the engineering workforce is ageing, with one fifth expected to have retired or be close to retirement by 2026.**
- **This may mean the engineering labour market becomes more global, with growing competition between countries to attract/retain engineering workers.**
- **Engineering may be able to mitigate against the challenges associated with an ageing population through innovations in health, medical transportation and the built environment.**
- **Engineering is likely to play a critical role in developing countries as they catch up to other countries in terms of critical infrastructure and related investment.**

Demographic changes will have significant long-term impacts on engineering industries and their labour markets.

Employment in engineering varies globally, but is significant in the UK. In 2019, EngineeringUK estimated that: almost one fifth of the UK's working population - 5.8 million people – are in employed engineering jobs. According to RSA analysis of the ONS Annual Population Survey, core and related engineering occupations as defined by EngineeringUK increased by 13 percent between 2011 and 2019 (a net increase of over 700,000 jobs). Generally speaking, engineering employment estimates are not readily available for many countries, and comparisons are rendered difficult by the differences in defining engineering occupations and industries. According to the 2016 Royal Academy of Engineering's Engineering and economic growth report, the countries with the highest percentage of people employed in engineering jobs were Sweden, Denmark, Netherlands, Japan, Switzerland, Norway, Luxembourg.[4]

4 Cebr for the Royal Academy of Engineering (2016) Engineering and economic growth: a global view. [PDF] Royal Academy of Engineering. Available at: www.raeng.org.uk/media/mp2odj00/final-cebr-report-12-09.pdf

Ageing workforces are a growing challenge across the globe. In the UK, the Engineering Construction Industry Training Board (ECITB) found that in the construction industry the rate of retirement amongst engineers will create recruitment challenges. An estimated 91,000 engineers and 29,000 engineering technicians are expected to have retired or be close to retiring by 2026, which amounts to one fifth of the entire UK engineering workforce and 18 percent of engineering technicians.[5] According to Blau and Weinberg, similar challenges are being experienced in the USA.[6,7]

Demographic shifts also impact the demand and supply of engineering, and affect movements of engineers within and between global regions. Across Africa there is an increasingly young population: African youth are expected to make up 42 percent of global youth by 2030. And 60 percent of the continent's population currently is under the age of 25.[8] It is forecast to have the largest workforce by 2035 at 1.1 billion people. Several countries regard science, technology, engineering and mathematics (STEM) education as necessary to escape economic insecurity and its social impacts, given the relationship between engineering, STEM graduates, and economic growth.[9] A concern, however, is that because STEM careers might pay more in other global regions, the continent risks losing many able engineers to other parts of the world.

In Asia and the Pacific region, an ageing population will present challenges that engineering can help tackle through innovations in health, medical transportation and the built environment.[10] Across the ASEAN countries – a collection of 10 Southeast Asian countries – the demographic trends are various, which might prompt greater labour movement within the region. While some countries such as Singapore, Brunei Darussalam and Thailand might indeed see an ageing labour force, Cambodia, Indonesia, the Philippines, and the Lao People's Democratic Republic, will still see an increased workforce in the next few decades.[11] 'Brain drain' is still a concern in the region. However, in the decade between 2000 and 2010, the number of post-secondary educated ASEAN emigrants to OECD countries increased from 1.7 million to 2.8 million. The prediction is now for an increase in movement within the region, due to high skills but unequal economic opportunities between ASEAN countries.

Critical infrastructure

In the context of emerging markets, population growth and urbanisation are also driving the demand for engineering, especially in terms of critical infrastructure. In emerging markets, engineers play a key role in infrastructure that provides necessary services such as energy, water and food security, transport, communication and physical and built infrastructure. Research by the Royal Academy of Engineering shows how deeply tied engineering, especially in terms of infrastructure and economic growth, is to development opportunities.[12] Further research supports the suggestion that investment in infrastructure acts to promote growth and productivity.

5 The Engineering Construction Industry Training Board (ECITB) (2020) Towards net zero: the implications of the transition to net zero emissions for the Engineering Construction Industry. [PDF] ECITB. Available at: www.ecitb.org.uk/wp-content/uploads/2020/03/Net-Zero-Report-Web.pdf
6 Blau, DM, Weinberg, BA (2017) Why the US science and engineering workforce is aging rapidly. [PDF] PNAS. Available at: www.pnas.org/doi/10.1073/pnas.1611748114
7 Frazer, A (2021) Women in engineering. [online] Available at: www.newengineer.com/blog/women-in-engineering-1512010 [Accessed 2023].
8 World Economic Forum (2022) Why Africa's youth hold the key to its development potential. Available at: https://www.weforum.org/agenda/2022/09/why-africa-youth-key-development-potential/. [Accessed 2023]
9 UNESCO, International Centre for Engineering Education (2021) Engineering for sustainable development: delivering on the Sustainable Development Goals. [PDF] UNESCO Available at: www.unesdoc.unesco.org/ark:/48223/pf0000375644.locale=en
10 UNESCO, International Centre for Engineering Education (2021) Ibid.
11 Batalova, J, Shymonyak, A, Sugiyarto, G (2017) Firing up Regional Brain Networks: The Promise of Brain Circulation in the Asean Economic Community. [PDF] Asian Development Bank. Available at: www.ukabc.org.uk/wp-content/uploads/2017/02/brain-networks-asean.pdf
12 Cebr for the Royal Academy of Engineering (2016) Op cit.

India is an example of a country where these links were exemplified in a boom in infrastructure and construction, which was expected to grow 7.4 percent between 2016 and 2021. Globally, India was the country with the most infrastructure projects in development or execution, amounting to over USD 25m in May 2022.[13.] Despite the setbacks from disruptions to supply chains due to the pandemic, infrastructure is still seen as an important driver of economic development for emerging markets.[14.]

Sectorally, the engineering fields in highest demand in the African continent are found to be agricultural engineering, civil engineering to support the development of agriculture and civil engineering for infrastructure development.[15.] Initiatives like the Belt and Road Initiative (BRI) will increase the demand for engineers by facilitating infrastructure projects developing roads, railways and ports across Africa, Central Asia and Europe.[16.]

1.2 Technological patterns and trends

This section considers and summarises the ways in which technological trends – including digitisation, automation, and decarbonisation – are impacting on the world of engineering and associated skills. We find that:

Key points

- **Digitisation and the Internet of Things will see increasingly smart cities emerge with their own engineering requirements. This will likely generate growing demand for high-tech roles, including in computer programming and IT.**
- **There are potential benefits to automation, with undesirable or dangerous jobs being replaced and de-risked.**
- **Discussion around technological innovation and the labour market often revolves around job losses; our analysis suggests engineering professionals' roles are at low risk from automation but that related roles might be more affected.**
- **Process, plant and machine operatives account for a small share of engineering employment but are likely to experience higher risks of automation and greater difficulties transitioning to new employment.**
- **Previous RSA analysis suggests that there is a significant sectoral dimension to automation and that workers in some parts of manufacturing may face the most acute impacts, while construction appears better insulated from these risks.**
- **Net employment impacts are estimated to be positive, both domestically and globally. Decarbonisation will rely on, and generate, a number of new engineering jobs and competencies, especially in low carbon energy generation and heating. While new jobs are expected to be well distributed, job losses will be concentrated in specific regions of the UK, such as those reliant on fossil fuel extraction.**

13 Statista (2022) Number of great infrastructure projects in development worldwide as of May 2022, by selected countries. [online] Available at: www.statista.com/statistics/1307599/big-infrastructure-onstruction-projectsworldwidebyelectedcountries/#:~:text=India%20was%20the%20country%20with,projects%2C%20and%20China%20with%201%2C175 [Accessed 2023].

14 Deloitte (2022) Infrastructure development as economic stimulus for emerging markets. [PDF] Deloitte. Available at: www2.deloitte.com/content/dam/Deloitte/global/Documents/Public-Sector/gx-gps-emerging-markets-infra-development-report.pdf

15 UNESCO, International Centre for Engineering Education (2021) Op cit.

16 UNESCO, International Centre for Engineering Education (2021) Ibid.

- **Decarbonisation will also necessitate large-scale changes in business models and production processes, especially in emission-heavy industries like cement, steel and car manufacturing. This will inevitably require shifts in the skills and approaches of engineers employed in those sectors.**
- **A shift to a more circular economy will likely see manufacturing jobs supplanted by roles in repairing, recycling and remanufacturing, with associated skills becoming more important.**
- **Globally, adaptation efforts will require engineering expertise in infrastructure such as flood defences and specific skills (such as risk assessment, probability modelling, geospatial engineering and data analytics).**

Digitisation

We refer to digitisation in cases "where technology turns physical goods and knowledge into data that can be captured, shared and replicated at low cost".[17.] Historically this began with the advent of personal computers, turning physical documents into virtual and editable files. Digitisation's second wave came with the advent of the internet, while a more recent iteration came about with the Internet of Things, a "vast network of internet-connected sensors that are collecting previously uncollectable data on objects and people, and on the wider environment".[18.] Recent and ongoing developments include the Industrial Internet of Things (IIoT) and smart cities.

Technology in focus: Internet of Things

Lloyd's Register Foundation (LRF) research has defined the Internet of Things as the network of technologies which interface and compute across the internet, largely without human intervention. It is often (but not always) a collection of small, low-powered devices designed to function as part of a coordinated system for data collection and analysis.[19.] It is broadly encompassing "everything connected to the internet, but increasingly it defines objects that talk to each other".[20.]

The number of internet-enabled devices has been ballooning in recent years. In September 2021, the number of connected IoT devices was growing 9 percent to 12.3bn globally.[21.] Its rapid growth has been driven by advances in sensors, data science and artificial intelligence (AI) technologies and a decrease in IoT infrastructure costs.

Use cases include: monitoring devices in manufacturing production lines, for example for quality controls; asset tracking tools; and fleet management, including for tracking vehicles, route optimisation, troubleshooting problems and location tracking. Some use cases require the coming together of IoT and other technologies: predictive maintenance relies on the interaction between IoT sensor data and AI. IoT can work closely with digital twins – virtual representations of a system that updates in real time – and can be blended with virtual reality (VR) and augmented reality (AR) to manage equipment and visual breakdowns in real time, augmenting IoT with big data allows for route, speed and fuel optimisation.

17 Dellot, B, Mason, R, Wallace-Stephens, F (2019) Coping with uncertainty in an age of radical technologies. [PDF] RSA. Available at: www.thersa.org/globalassets/pdfs/reports/rsa_four-futures-of-work.pdf

18 Dellot, B, Mason, R, Wallace-Stephens, F (2019) Ibid.

19 Creese, S et al (2020) Foresight review of cyber security for the Industrial IoT: Enabling safer more resilient infrastructures. [PDF] Lloyd's Register Foundation. Available at: www.lrfoundation.org.uk/en/news/cybersecurity-foresight-review/

20 Burgess, M (2018) What is the Internet of Things? WIRED explains. [online] Available at: www.wired.co.uk/article/internet-of-things-what-is-explained-iot#:~:text=increasingly%20connected%20world.-What%20is%20the%20Internet%20of%20Things%3F,%22talk%22%20to%20each%20other [Accessed 2023].

21 Satyajit, S (2023) State of IoT 2023: Number of connected IoT devices growing 16 percent to 16.7 billion globally. [online] Available at: www.iot-analytics.com/number-connected-iot-devices/ [Accessed 2023].

Technology in focus: smart cities

IoT in the built environment is at the basis of the development of smart cities. This is particularly important as 56 percent of the world's population lives in cities, with urban population set to double its size by 2050.[22] This will bring challenges such as increased and accelerated demand for affordable housing and infrastructure, basic services and jobs. The World Bank shows that 50 percent of people displaced because of conflict live in urban areas. Cities also have an impact on climate change and are in turn exposed to climate risk and disaster risk.

A key technology in smart cities is IoT that is used in smart lighting systems, traffic management, waste management, parking, utility meters, city grids. Singapore introduced its smart nation initiative in 2014.[23] It introduced a smart digital health system that normalised video consultations at an early stage, and wearable IoT sensors to monitor patients. In 2021 Singapore announced plans for a new 'eco-smart' city that is entirely vehicle free above ground, in Tengah in West Singapore. The development is supposed to house five residential districts with 42,000 houses, and safe zones for both pedestrians and cyclists.[24]

Songdo, in South Korea, was dubbed 'the first smart city', situated in Songdo International Business District, and costing around USD 40bn.[25] It is meant to be high-tech and low carbon. It includes innovative smart waste management systems that automatically sort and recycle waste, bringing Songdo's recycling rate to 76 percent.[26] It has over 20m square feet of LEED certified space ("the highest concentration of LEED certified projects in the world").[27] However, it has failed to attract the anticipated number of residents, with just over 100,000 inhabitants, one third of the original goal of 300,000. This would point to the importance of human-centred design alongside smart features, pointing at the multidisciplinary skills needed for, in this case, the effective development of liveable smart cities.

Digitisation is often reflected in employment estimates, and changes. According to RSA analysis of the Annual Population Survey, core and related engineering occupations as defined by EngineeringUK increased by 13 percent between 2011 and 2019 (a net increase of over 700,000 jobs).[28] The fastest growing roles were mostly professional and managerial roles. This includes many high-tech roles such as computer programmers and IT business analysts, architects and systems designers. Similar research by the Organisation for Economic Co-operation and Development (OECD) shows that growth in jobs is highest for engineering and information communication technology (ICT) in response to the digital transformation of economies worldwide.[29] In the US, research by Brookings shows that several highly digitised occupations such as electronics engineers and aerospace engineers, became more digitised between 2002 and 2016. However, modest decline was seen in other engineering-related highly digitised occupations such as computer hardware engineers.[30]

22 The World Bank (nd) Urban development. [online] Available at: www.worldbank.org/en/topic/urbandevelopment/overview [Accessed 2023].
23 Holland, O (2021) Singapore is building a 42,000-home eco 'smart' city. [online] Available at: www.edition.cnn.com/style/article/singapore-tengah-eco-town/index.html [Accessed 2023].
24 Holland, O (2021) Ibid.
25 Plasticexpert (nd) Songdo, South Korea. [online] Available at: www.plasticexpert.co.uk/songdo-south-korea/ [Accessed 2023].
26 Plasticexpert (nd) Songdo, South Korea. Ibid.
27 Poon, L (2018) Sleepy in Songdo, Korea's smartest city. [online] Available at: www.bloomberg.com/news/articles/2018-06-22/songdo-south-korea-s-smartest-city-is-lonely [Accessed 2023].
28 Office for National Statistics (2016) Labour Force Survey – user guidance. [online] Available at: www.webarchive.nationalarchives.gov.uk/ukgwa/20160105231515/http://www.ons.gov.uk/ons/guide-method/method-quality/specific/labour-market/labour-market-statistics/index.html [Accessed 2023].
29 OECD (2017) Meeting of the OECD council at ministerial level. [PDF] OECD. Available at: www.oecd.org/mcm/documents/C-MIN-2017-3-EN.pdf
30 Muro, M, Liu, S, Whiton, J, Kulkarni, S (2017) Digitalization and the American workforce. [PDF] Metropolitan Policy Program at Brookings. Available at: www.brookings.edu/wp-content/uploads/2017/11/mpp_2017nov15_digitalization_full_report.pdf

However, this is not the case equally across the globe. Data from the United Nations Industrial Development Organization (UNIDO) shows the changing profile of the engineering sector between countries. These see differing rates of growth in different industries, split between industrial economies and other industrialising economies. In industrial economies the highest growing industries year on year were computer, electronic and optical products, wearing apparel, and beverages, while in industrialising economies, growth was highest in electrical equipment, the manufacturing of motor vehicles, trailers and semi-trailers, and the manufacturing of wearing apparel.[31]

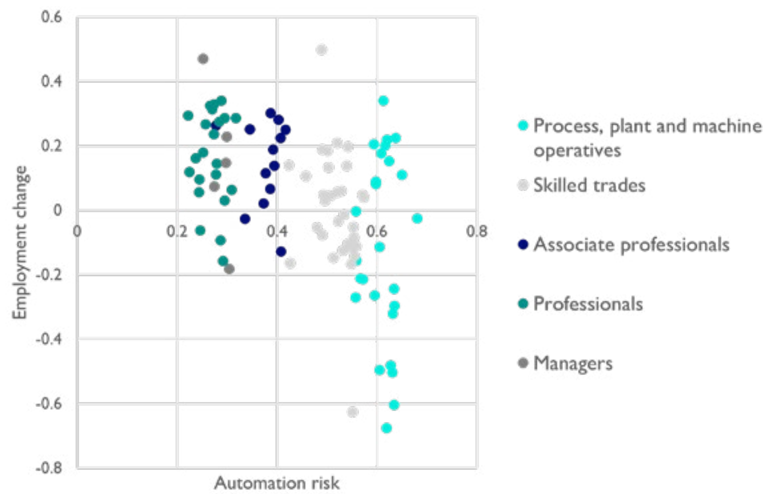
Automation

Debates about the future of work have been dominated by attempts to predict the number of jobs that will be replaced by AI and robots. The MIT Technology Review found that more than 18 separate studies have been published since Frey and Osborne estimated that 47 percent of US jobs could be automated in the next 10 to 20 years.[32] These predictions draw on expert opinion to understand which jobs could technically be automated. But they can often feel speculative and out of touch with economic reality.[33]

While engineering professionals are at a relatively low risk of automation, our analysis suggests that automation may be taking place across several roles related to engineering. However, this prospect should not engender fatalism. Technology could liberate some workers from tasks that are dirty, dull or dangerous and free up their time to focus on activities that cannot be performed by robots or algorithms.

However, not all workers may be well positioned to benefit from these shifts. As Figure 1.1 (below) shows, our analysis of skills and employment data finds that while process, plant and machine operatives account for a relatively small share of engineering employment in the UK, these roles are more exposed to automation. Many of these roles are at high risk of automation and experienced negative employment growth between 2011 and 2019. Several skilled trades roles also experienced a decline, particularly those involved in metal work. (This analysis is outlined in greater detail in Section 2.2).

Figure 1.1: Employment growth by automation risk and major occupational group (RSA analysis of Annual Population Survey, ONS automation risk data and EngineeringUK engineering footprint)



31 United Nations Industrial Development Organization (UNIDO) (2023) Report on the world manufacturing production. [online] Available at: www.unido.org/resources-statistics/quarterly-report-manufacturing [Accessed 2023].
32 Winick, E (2018) Every study we could find on what automation will do to jobs, in one chart. [online] Available at: www.technologyreview.com/2018/01/25/146020/every-study-we-could-find-on-what-automation-will-do-to-jobs-in-one-chart/ [Accessed 2023].
33 Wallace-Stephens, F, Morgante, E (2021) Good work innovations in Europe: reimagining the social contract. [PDF] RSA. Available at: www.thersa.org/reports/good-work-innovations-in-europe-reimagining-the-social-contract

Separate RSA analysis suggests that there is a significant sectoral dimension to automation and that workers in some parts of manufacturing may face the most acute challenges. Overall, the manufacturing sector has experienced modest growth in the UK in recent years, reversing its long-term decline since the 1980s. However, some sub-sectors such as manufacture of food, metals, plastics and chemicals have experienced a decline. Meanwhile, higher value manufacturing sectors such as pharmaceuticals, cars and other transport equipment have experienced growth.[34.]

Construction has a lower automation risk than most manufacturing sectors. Activities are considered to be less repetitive than in manufacturing, in part due to the more unpredictable nature of environments in the sector. Most construction projects are unique and respond to different customer demands and architectural design. Technological transformation in construction might take different shapes, including the automation of physical tasks on construction sites and a shift to modular construction. 3D printing has the potential to revolutionise aspects of the sector, but for these purposes the technology is in its relative infancy and human discretion will retain a critical importance.[35.] According to analysis by McKinsey, automation could have a straightforward positive effect on employment in the industry. The authors predict that globally, construction jobs will grow in the next decade, with up to 200m being created to support new infrastructure projects and boost affordable housing supply.[36.]

Globally, the scale of the challenge differs between countries. Recent data from RBC Global Asset Management shows the level of exposure of manufacturing of basic goods, opportunities for reskilling, and onshoring potential. Among emerging markets considered, South Africa, Turkey and Mexico were found to have the greatest risks, while Taiwan, UAE and Malaysia were among the lowest end of the spectrum.[37.] These three factors interact differently in different countries. China, for example, has high exposure to manufacturing but has low risk in terms of reskilling, decreasing the risks to manufacturing on the whole. UAE's low risk level comes from the fact that it has low economic dependency on manufacturing, reflected in its relatively low share of GDP. On the other hand, many countries in Sub-Saharan Africa are yet to transition from an agricultural economy to an industrial one.

Several global studies also illustrate the potential scale and impact of automation in manufacturing. The International Federation of Robotics (IFR) highlight that orders of industrial robots have doubled between 2013 and 2017. The share of industrial robot sales amounted to USD 16.2bn globally in 2017, while service robots reached USD 6.6bn.[38.] Eurofound have put forward two scenarios for the potential impact of automation in this sector. In a high cost, low uptake scenario, they estimate the employment in manufacturing will be 20 percent lower by 2030. While in a low cost, high uptake scenario, this rises to 30-35 percent.[39.]

34 Wallace-Stephens, F, Morgante, E (2021) Ibid.
35 Digital Builder, (2021) Harnessing the power of 3D printing in construction, Digital Builder [podcast] December 2021. Available at: www.constructionblog.autodesk.com/digital-builder-podcast-ep-23/ [Accessed 2023].
36 Wallace-Stephens, F, Morgante, E (2021) Op cit.
37 RBC Emerging Markets Equity Team (2021) The future of emerging markets: Manufacturing. [online] Available at: www.rbcgam.com/en/ca/article/the-future-of-emerging-markets-manufacturing/detail [Accessed 2023].
38 International Federation of Robotics (IFR) (2018) Global industrial robot sales doubled over the past five years. [online] Available at: www.ifr.org/ifr-press-releases/news/global-industrial-robot-sales-doubled-over-the-past-five-years [Accessed 2023].
39 Donald, S (2019) The future of manufacturing in Europe. [PDF] Eurofound. Available at: www.eurofound.europa.eu/publications/report/2019/the-future-of-manufacturing-in-europe

Technology in focus: robotics and autonomous systems

Recent LRF research defines robotics and autonomous systems as the interconnected, interactive, cognitive and physical tools that are "able to variously perceive their environments, reason about events, make or revise plans and control their actions".[40.] Collaborative robots (or 'cobots') are experiencing an increase in demand. Cobots run alongside, rather than replace, humans and contribute to increased productivity with improved cost efficiency.[41.]

Adoption of RAS is being driven by a variety of factors, such as increases in efficiency potentials in labour and products, labour shortages, and aging workforces in many countries.[42.] In the UK, the introduction of temporary tax incentives are also predicted to boost automation and adoption of emerging technologies.[43.]

In terms of classic industrial robots, these are more evidently economically valuable to manufacturing enterprise which are large, and involve repetitive tasks and the production of single items in large quantities.[44.] Small and medium enterprises (SMEs), however, are typically more focused on high-variety low-volume production, and might therefore see less value in adopting robots given their suitability to high-volume production and their high costs.

Use cases in engineering include the robotic fulfilment centres that assemble packages and dispatch goods; unmanned aerial vehicles (UAVs) that deliver packages or carry out mapping and repairing in offshore oilfields and nuclear facilities; assistive exoskeletons; interactive companions for the elderly and isolated.

RAS presents specific safety opportunities and challenges that will be explored further in following chapters. Opportunities to increase safety include substituting humans in hazardous environments, decreasing the risk of fatigue and injuries in the case of exoskeletons, and increasing safety for the environment through efficiencies in resource-use. The main safety challenges come from the interactions between humans and machines, and the potential of a replacement or rebound effect due to said efficiencies.

Decarbonisation

Many countries are investing in green jobs as a strategy for post-Covid recovery. According to the UK's Net Zero Strategy, government investment will help create and support up to 440,000 highly skilled, high paid, green jobs by 2030.[45.] While separate research commissioned by the Local Government Association (LGA) suggests that as many as 700,000 jobs could be created in the low carbon and renewable energy economy, rising to over 1.2m by 2050.[46.]

Engineers of different stripes will play a critical role in the shift to net zero. The LGA suggests that 46 percent of low carbon jobs will concentrate on electricity generation and low carbon heat in homes and businesses. These include jobs in manufacturing wind

40 Lane, D et al (2016) Foresight review of robotics and autonomous systems: serving a safer world. [PDF] Lloyd's Register Foundation. Available at: www.lrfoundation.org.uk/496934/siteassets/pdfs/lrf_foresight_review_of_robotics_and_autonomous_systems.pdf
41 Michie, J (2021) The future of cobots. [online] Available at: www.searchingindustrial.com/media/4174/the-future-of-cobots [Accessed 2023].
42 International Federation of Robotics (IFR) (2021) Robot density nearly doubled globally. [online] Available at: www.ifr.org/ifr-press-releases/news/robot-density-nearly-doubled-globally [Accessed 2023].
43 Sewtec (nd) How the tax super-deduction can benefit manufacturers investing in new automation equipment. [online] Available at: www.sewtec.co.uk/insight/super-tax-deduction-and-automation/ [Accessed 2023].
44 Sanneman, L, Fourie, C, Shah, J (2020) The State of Industrial Robotics: Emerging Technologies, Challenges, and Key Research Directions. [PDF] MIT Work of the Future. Available at: www.workofthefuture.mit.edu/wp-content/uploads/2020/11/2020-Research-Brief-Sanneman-Fourie-Shah.pdf
45 HM Government (2021) Net zero strategy: build back greener. [PDF] HM Government. Available at: www.assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf
46 Local Government Association (2020) Local green jobs – accelerating a sustainable economic recovery. [online] Available at: www.local.gov.uk/local-green-jobs-accelerating-sustainable-economic-recovery [Accessed 2023].

turbines, deploying solar panels, installing heat pumps, maintaining infrastructure and constructing nuclear reactors.[47.] Over one fifth (21 percent) of net zero jobs by 2030 will be involved in installing energy efficiency products such as insulation, lighting and building control systems. While 14 percent of these jobs will be directly involved in manufacturing low-emission vehicles and associated infrastructure such as batteries and charging points. Jobs related to the research and development of low carbon alternative fuels such as hydrogen are also expected to experience growth. For example, BP is developing plans to create the UK's largest low carbon hydrogen hub in Teesside.[48.]

Several studies suggest that the employment impacts of the transition to net zero will be net positive. The ILO's World Employment and Social Outlook 2018: Greening with jobs calculates that 24m new jobs will be created globally by 2030 if sustainable practices are adopted.[49.]

However, it is also expected that these effects will be felt unevenly across and within countries. In terms of global regions, one prediction, if policies are not changed, estimates net job creation in the Americas (3m, equivalent to 0.45 percent), Asia and Pacific (14m, or 0.32 percent) and Europe (2m, or 0.27 percent), while there could be net losses in the Middle East of 300,000 jobs (-0.48 percent) and 350,000 in Africa (-0.04 percent).[50.] Research by the WWF shows that if globally there was a shift of subsidies of USD 500bn from those that support fossil fuels, over-fishing and unsustainable agriculture, to greener activities, 39m new jobs could be created, largely in east Asia-Pacific, South Asia and Sub-Saharan Africa.[51.]

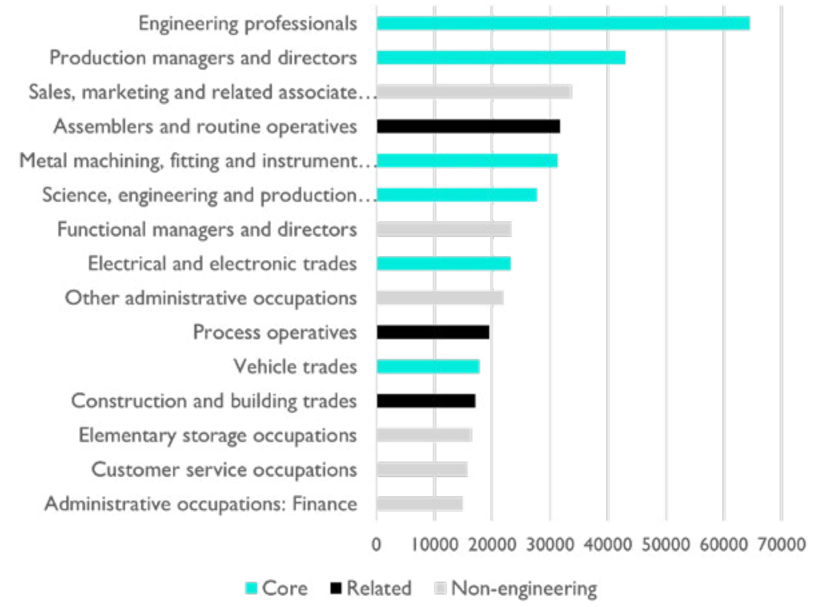
Disparities will also be felt within countries: the European Investment Bank predict that green jobs, such as those in renewable energy and recycling, will be created in many regions, but that job losses are likely to be concentrated in a few, particularly those dependent on industries like fossil fuel extraction or car manufacturing.[52.]

The transition to net zero will entail large-scale changes in business models and production processes. Like automation, decarbonisation will have implications across different sectors for the number and types of jobs available. The UK government's Net Zero Strategy also points out the necessity of transformation where it suggests that "it [decarbonisation] means no longer burning fossil fuels for power or heating; it means new ways of making concrete, cement, steel; it means the end of the petrol and diesel engine".[53.] Previous RSA analysis shows that the engineering industries with the current highest greenhouse gas emissions are most likely to face the biggest changes over the coming years with some already seeing declining employment rates.

In this context, several engineering industries appear likely to experience transformation or decline. Most of these industries, predictably, relate to fossil fuel and energy production, or emission-intensive heavy industry such as cement and steel. Within these industries, the largest employment group is engineering professionals.[54.]

47 HM Government (2021) Net zero strategy: build back greener. Op cit.
48 BP United Kingdom (2023) Three bp-led low carbon projects in Teesside continue to make progress towards development [online] Available at: www.bp.com/en_gb/united-kingdom/home/news/press-releases/three-bp-led-low-carbon-projects-in-teesside.html [Accessed 2023].
49 International Labour Office (ILO) (2018) Greening with jobs. [PDF] ILO. Available at: www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_628654.pdf
50 International Labour Office (ILO) (2018) Ibid.
51 Taylor, M (2021) Millions of green jobs can be created by ending subsidies that harm nature, WWF says. [online] Available at: www.weforum.org/agenda/2021/09/subsidies-green-jobs-wwf-report-nature-environment [Accessed 2023].
52 Wallace-Stephens, F, Morgante, E (2021) Op cit.
53 HM Government (2021) Net zero strategy: build back greener. Op cit.
54 The engineering footprint defines core occupations as those that are primarily engineering-based and require the consistent application of engineering knowledge and skills to execute roles effectively. Related occupations include roles such as architects and construction workers that require some engineering skills, but where other skills are considered more important to execute the role effectively.

Figure 1.2: Largest engineering and other occupation groupings in selected industries that will be impacted by decarbonisation (RSA analysis of Annual Population Survey and UK Engineering Footprint)



Other ways in which these industries, and thus engineering jobs, might be impacted is through a shift to a more circular economy. The current economic model could be described as linear: extract, manufacture, use and discard. In the circular economy, products are designed to have longer lifecycles, be serviced and repaired, reused or recycled. Aside from the potential greenhouse gas emission reductions, circular economy approaches can have wider environmental benefits by reducing demand on natural resources.

The shift to a circular economy is not expected to lead to a net loss of employment activity. While traditional manufacturing firms will see a decline in demand for their products, new jobs will be created in repair, recycling and remanufacturing. According to the ILO, the manufacture of steel will experience the greatest decline in absolute terms, with 28m jobs lost globally. However, they expect 31m jobs will be created in the processing of secondary steel into new steel. Similar dynamics are expected to take place across many manufacturing sectors, glass and glass products.[55.]

Engineering will not only be crucial in decarbonising various sectors of the economy, but also in adapting to a changing climate. Rising sea levels, and other phenomena associated with climate change are also creating demand for engineers to provide adaptation infrastructure in many parts of the world. Many regions near the equator will see decreases in precipitation and drought. Low-lying coastal regions will experience more flooding. This includes large areas of Bangladesh and the Netherlands, and small island nations in the Pacific.[56.] Engineers will be crucial in developing infrastructure, risk assessment and probability modelling, and different codes and standards in the built environment including bridges, to ensure that infrastructure is resilient to extreme climatic events.[57.]

According to research by UNESCO, engineering demand might come from the need for adaptation infrastructure, especially to make rapidly urbanising cities more resilient to climate change impacts, such as changes in transportation, water, energy and

55 Wallace-Stephens, F, Morgante, E (2021) Op cit.
56 Masterson, V, Hall, S (2022) Sea level rise: everything you need to know [online] Available at: www.weforum.org/agenda/2022/09/rising-sea-levels-global-threat/ [Accessed 2023].
57 UNESCO, International Centre for Engineering Education (2021) Op cit.

communication systems.[58] This is key as, by 2050, more than two-thirds of the world is predicted to live in cities. Climate change will make engineering solutions for integrated water management systems essential, especially in arid areas. Smart sustainable cities are a priority in many countries, with India, for example, establishing a target of building 100 smart cities by 2022. In this sense, geospatial engineering, data analytics and building information modelling will be key.[59]

Technology in focus: hydrogen

Hydrogen as a fuel source has been touted as the key to achieving ambitious climate goals and shift towards a decarbonised economy, with the potential of decreasing greenhouse gas emissions in many sectors. Hydrogen can react with oxygen to produce heat; in a fuel cell, this reaction can be used to produce clean, efficient, emissions-free electricity.[60] Recent research by the International Energy Agency (IEA) shows that demand for hydrogen is rising, having already grown more than threefold since 1974.[61]

Currently, most of the world's hydrogen is 'grey hydrogen', which means that it is produced from fossil fuels through processes such as steam reforming, using methane, propane, gasoline or coal.[62] 'Blue hydrogen' refers to hydrogen that is produced using fossil fuels, but where the CO2 produced is captured and stored. The ultimate goal is to increase the production of 'clean hydrogen' or 'green hydrogen', which is produced through electrolysis of water using renewable power source electricity. However, this type of hydrogen is currently much more expensive than natural gas. Falling renewable energy prices and improvements in technology that are making electrolysers cheaper are contributing to the falling costs of green hydrogen production.

The main safety use case for hydrogen is the potential it has to increase safety for the environment. It is used to decarbonise the production of steel – by substituting coal in the production process. Recent examples include the cooperation between Ørsted, a Danish multinational and largest offshore wind power company, and South Korean steelmaker POSCO on a feasibility study for the production of green hydrogen to prepare for supply of 'hydrogen steel'.[63] Hydrogen fuel cells can support decarbonising the shipping industry and maritime sector. Maritime shipping accounts for 3 percent of all global emissions, but could rise to 10 percent if plans to decarbonise are not fast enough.[64] Maersk aims to create the world's first carbon-neutral liner vessel fuelled by methanol in 2023, earlier than the original 2030 plan.[65]

While the potential use cases are numerous, there is a worrying trend of assuming clean hydrogen is the default solution to many energy issues. Research shows that hydrogen use should be focused on use cases where it is difficult to use cheaper, cleaner technologies and where clean hydrogen can use existing infrastructure.[66] It is meant to support decarbonisation of 'hard to abate' heavy industries like long-haul transport, chemicals, aviation, and iron and steel.[67] While currently it is transported through dedicated pipelines, lower concentrations of hydrogen can be transported in existing natural gas pipelines. However, pure hydrogen transportation would require major restructuring of the existing pipelines to guarantee safety.[68]

58 UNESCO, International Centre for Engineering Education (2021) Ibid.
59 UNESCO, International Centre for Engineering Education (2021) Ibid.
60 The Fuel Cell and Hydrogen Energy Association (FCHEA) (nd) Fuel cell basics. [online] Available at: www.fchea.org/fuelcells
61 International Energy Agency (IEA) (2019) The future of hydrogen. [PDF] IEA Available at: www.iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf
62 Cho, R (2021) Why we need green hydrogen. [online] Available at: www.news.climate.columbia.edu/2021/01/07/need-green-hydrogen/ [Accessed 2023].
63 Toyama, N (2022) Green hydrogen booms in Asia as companies rush into projects. [online] Available at: www.asia.nikkei.com/Spotlight/Environment/Green-hydrogen-booms-in-Asia-as-companies-rush-into-projects [Accessed 2023].
64 Thomas, D (2021) Amazon, Ikea and Unilever pledge zero-carbon shipping by 2040. [online] Available at: www.bbc.com/news/business-58970877 [Accessed 2023].
65 Maersk (2021) Moller, AP - Maersk will operate the world's first carbon neutral liner vessel by 2023 – seven years ahead of schedule. [online] Available at: www.maersk.com/news/articles/2021/02/17/maersk-first-carbon-neutral-liner-vessel-by-2023 [Accessed 2023].
66 Hegnsholt, E et al (2019) The real promise of hydrogen. [online] Available at: www.bcg.com/publications/2019/real-promise-of-hydrogen [Accessed 2023].

67 International Energy Agency (IEA) (2019) Op cit.
68 Cho, R (2021) Op cit.

CHAPTER 2: THE ENGINEERING SKILLS LANDSCAPE

The engineering skills landscape

This chapter looks at the current landscape for engineering skills. Through a review of skills frameworks for engineering in different global contexts, it sets out the skills that are felt to be the most important now and in the near future. In turn, through novel analysis of data from the European Skills, Competencies, Qualifications and Occupations framework, it explores the extent to which those skills will be needed in future. By forecasting the respective automation risks of different skills, it offers insights for employers and employees in the sector to develop capabilities that are futureproof.

Key points

From our landscape review, four distinct categories of skills emerged: **technical, digital, safety** and **transferrable** skills. These categories were identified through our landscape scan, ESCO data, and consultation with industry professionals to maximise their comprehensiveness and practical value. **The most pertinent and common skills within engineering identified under each category are outlined in the table below.**

Skills category	Summary of key skills
Technical: skills relating directly to specialist engineering knowledge and capabilities.	• Designing, testing and evaluating systems, equipment and products • Collecting, documenting and interpreting technical information • Data and statistical analysis • Technical and scientific knowledge development (ie, staying on top of new developments in field)
Digital: skills relating to digital knowledge and capabilities.	• Computer programming • Designing, testing and evaluating digital systems • Using computer aided design tools • Managing and analysing digital data • Using digital tools for automation • Digital literacy
Safety: skills relating directly to safety knowledge and capabilities.	• Inspecting equipment and systems • Ensuring compliance with health and safety rules • Ensuring compliance with environmental rules • Formulating safety policy and procedures • Carrying out risk analysis and management
Transferable: general skills that could be adapted to other professional contexts, engineering or otherwise.	• Creative problem solving • Leadership • Ethics • Communication • Teamwork and collaboration • Project management

Our scan finds, however, a number of **current skills shortages** owing to a range of factors, including:

- **Strong competition for skilled candidates**
- **A shortage of applicants with appropriate qualifications**
- **And a lack of awareness among young people of the educational routes into engineering.**

We also assess the **automation risk** faced by different skill sets and roles within engineering. We find that the **lowest risk occupations are typically managers, professionals and technicians,** while **skilled tradespeople and manual workers such as manufacturing process operatives typically have a higher risk of automation.** Workers in these jobs may struggle to transition to other roles due to their particular (less transferrable) skills, qualifications and educational backgrounds.

2.1 Current skills shortages

The World Economic Forum has identified growing demand for roles in engineering. These range from established roles such as data analysts, AI and machine learning specialists, and robotics engineers, to new emerging roles such as process automation specialists, information security analysts and Internet of Things specialists.[69.] These demands should be seen in the context of long-standing skills shortages in the engineering sector. The Recruitment & Employment Confederation (REC) JobsOutlook Engineering survey found that technical functions have been consistently voted by UK employers as among the top three most challenging to fill.[70.]

Shortages of appropriately skilled workers are the result of various factors, including strong competition for skilled candidates, a shortage of applicants with appropriate qualifications, and a lack of awareness among young people of the educational routes into engineering. But, as one might expect, this varies globally. The Royal Academy of Engineering's Global Capability Review from 2016 included a report from Sir James Dyson that his company "can fill all its engineering vacancies in Singapore and Malaysia but struggles to fill positions in the United Kingdom".[71.] Similarly, UNESCO data shows that emerging economies are leading the way in the proportion of students in tertiary education enrolled in engineering, manufacturing and construction programmes. Iran, Ethiopia, the Republic of Korea and Mexico perform strongly in engineering course enrolments, for example. In the case of Ethiopia and Mexico, they have introduced policies targeted at increasing graduates in these sectors; in the case of Iran, there are indications that its economy is as yet unable to absorb the number of graduates in these fields.[72.]

Nations' capacity to respond to increased skills demands and shortages in engineering also varies. A recent report on countries in the Southern African Development Community (SADC) shows that the increase in demand for engineers has prompted the proliferation of post-secondary education institutions offering engineering qualifications, but in a context of "inadequate resourcing, critical shortage of academics, [and] poor quality of graduates".[73.] From this perspective, shortages in the industry reflect neither a shortage of interested graduates nor available courses, but a shortage of qualified and experienced staff to instruct them.

69 Shine, I, Whiting, K (2023) These are the jobs most likely to be lost – and created – because of AI. [online] Available at: www.weforum.org/agenda/2023/05/jobs-lost-created-ai-gpt/ [Accessed 2023].
70 Recruitment & Employment Confederation (nd) JobsOutlook. [online] Available at: www.rec.uk.com/our-view/research/jobs-outlook?&q=&type=research&category=317&sortBy=Most%20popular&page=1 [Accessed 2023].
71 Cebr for the Royal Academy of Engineering (2016) Op cit.
72 Cebr for the Royal Academy of Engineering (2016) Ibid.
73 SADC (2018) Engineering Numbers and Needs in the SADC Region. Gaborone: SADC. [PDF] Available at: tis.sadc.int/files/9616/3117/4900/Engineering_Numbers_and_Needs_in_SADC.pdf [Accessed 2023]

Skills frameworks

This analysis draws on a wide variety of skills frameworks. But what are they, and what can they tell us about the future of skills in engineering? Put simply, skills frameworks outline the competencies and skills required to do different jobs. They provide valuable insights into different nations', industries' and specialisms' perceptions of current and emerging skills demands.

They also have practical value. They offer a common language for different actors in the sector to talk about, and respond to, skills needs. As a result, they can support employers to invest in more appropriate training, develop new progression pathways or align job design and recruitment with the changing needs of industry. Finally, they give learners and educators a means of communicating their existing skills effectively and making better decisions about upskilling and reskilling opportunities. Educators meanwhile can use skills frameworks to design training programmes that better align with emerging skills demands.

There are several existing engineering skills frameworks, but those of particular relevance to this research include:

- The UK Standard for Professional Engineering Competence and Commitment (UK-SPEC) capturing the requirements that people must meet to become registered as an engineering technician (EngTech), incorporated engineer (IEng) or chartered engineer (CEng).[74.]
- O*NET (Occupational Information Network), a US taxonomy and database of occupational information, with standardised and occupation-specific descriptors for a range of sectors and roles.[75.]
- SkillsFuture Singapore, which coordinated the country's skills needs and provision through lifelong learning opportunities.[76.]
- The European Skills, Competences, Qualifications and Occupations 'dictionary' which "[describes], identifies and classifies] professional occupations and skills relevant for the EU labour market and education and training".[77.]

What we did:

Literature and landscape review:

The review drew on engineering skills frameworks and related reports from the past 10 years. In scope were frameworks covering both general engineering skills – across all engineering professions – and those relating to specific types of engineering or engineering related roles. While the review was global in nature, sources primarily came from Europe, North America and Oceania.

See Appendix 1 for further information on our sources and methodology.

Analysis of ESCO skills-occupation data:

The ESCO is one of the most well known and widely used skills frameworks. It has been developed and maintained by the European Commission. Most pertinently for this analysis, the ESCO Skill-Occupation Matrix Tables include scores that indicate the prevalence of different skills in various occupations. We use these scores as a proxy for

74 Engineering Council (nd) UK-SPEC. [online] Available at: www.engc.org.uk/ukspec [Accessed 2023].
75 O*NET (nd) Soft skills custom list. [online] Available at: www.onetonline.org/skills/soft/ [Accessed 2023].
76 SkillsFuture (2023) About SkillsFuture Singapore. [online] Available at: www.skillsfuture.gov.sg/aboutssg- [Accessed 2023].`
77 European Commission (2022) What is ESCO? [online] Available at: www.esco.ec.europa.eu/en/about-esco/what-esco [Accessed 2023].

the importance of a given skill in the current labour market.[78]

In turn – presuming a similar distribution of skills between Europe and the UK – we mapped the resulting skills footprint – reflected in numerical scores to reflect prevalence for each skill type - from the European ESCO data to UK employment statistics to give a proxy for the prevalence of those skills in the UK. From this, we could identify the share of these skills in engineering occupations specifically.

Finally, we used relative ratings of the risk of automation for all occupations and applied these to those engineering occupations and skills, as are shown through the 'heat maps' explained in more detail below. This enabled us to highlight the extent to which different skills will be transferable into future engineering roles, and which roles – and employees – need most active upskilling and development for greater resilience.

A fuller account of the methodology behind this analysis can be found in Appendix 2.

2.2 Automation risk

According to our analysis of the engineering occupations and skills most vulnerable to automation, the lowest risk occupations **are typically managers, professionals and technicians**. On the other hand, **skilled tradespeople and manual workers such as manufacturing process operatives typically have a higher risk of automation.** This gives some indication as to the roles and employees who could most benefit from upskilling in more transferable skills for the future engineering landscape. (See Figure 2.1).

Figure 2.1: Example of engineering occupations by automation risk quartile

Automation risk quartile	Example occupations
1 (Low)	• Manufacturing and construction managers • Engineering professionals • Computer programmers, systems analysts, other IT professionals • Safety professionals (eg quality assurance and regulatory professionals, environmental professionals)
2 (Low-medium)	• Engineering technicians • Manufacturing and construction supervisors • Mechanical engineers • Safety technicians and associate professionals
3 (Medium-high)	• Electrical trades (eg electricians telecoms engineers) • Vehicle trades (eg boat builders, aircraft maintenance) • Machinists (precision instrument makers, production maintenance fitters)
4 (High)	• Metal workers eg welding trades, smith and forge workers • Plant and process operatives eg paper, plastics factory workers • Quarry workers, coal mine operatives

78 ESCO provides the following advice on interpretation of the raw data, which we converted to rankings in our analysis: tables show in percent values the distribution of skills (or skills groups) among occupations or (occupation groups) eg when looking at clerical support workers, one can observe that workers in this group have a higher share of communication, collaboration and creativity skills, while they have a low share of handling and moving skills.

This section reflects on and summarises the **most pertinent skills for engineering professions.** From a review of current skills frameworks, these emerge under the following categories: technical, digital, safety and transferable skills. Each of these will be explored in more detail below, exploring both their current importance in the sector and how automation will affect their relevance in future. This in turn offers insights into impacts on different parts of the workforce – from managerial and highly technical occupations through to more operational roles – and the skills and professions that will offer greatest resilience to automation risks.

Technical skills

- **Two thirds of UK employers in engineering report gaps in technical skills.**
- **The most important technical skills appear to relate to monitoring and testing equipment, analysing data, designing systems or products and interpreting technical documents.**
- **While some of these will be domain specific, many could be considered 'core' skills that cut across different roles, which could help to provide resilience for roles most at risk of automation.**

The Institution of Engineering and Technology skills and demand in industry 2021 survey reports that 67 percent of employers in the United Kingdom report gaps in technical skills.[79] By far the top technical skill identified as lacking in the survey is "specialist skills/ knowledge needed for the role", with 63 percent of respondents identifying this as a problem area.

Technical skills refer to specialist capabilities closely tied to engineering as a profession. There were numerous references to these sorts of skills in the frameworks we studied. For example, UK-SPEC references the need to "maintain and extend a sound theoretical approach to the application of technology in engineering practice" and "use appropriate scientific, technical or engineering principles" for both engineering technicians and incorporated engineers. Similarly, SkillsFuture Singapore highlights IoT management, data and statistical analytics and building information modelling applications as among the 'skills in demand'. Finally, the ESCO includes several technical engineering skills, with the most important appearing to relate to monitoring and testing of equipment, analysing data, designing products and interpreting technical documents.

Clearly, many of these skills will be important for engineering professionals that are less at risk of automation, with engineering professionals and other specialist analysts and programmers in the lowest risk category. However, while technical, some of these skills could also be considered generalisable core skills that could provide pathways for those at greater risk to a position of greater security. This offers some insights into the kinds of skills that policy and providers could prioritise not only to futureproof the sector, but also the security of those occupying at-risk roles.

Interpreting the automation heat maps

The heat maps below reflect the results of the ESCO data analysis on engineering skills importance and assessments of relative automation risk. In accordance with the findings from our literature review, these were grouped into technical, transferable, digital or safety skills, as can be seen in the tables below.

The rows of each table set out the most prevalent skills within each skill category, as identified in the ESCO analysis. The columns of each table indicate the level of

79 The Institution of Engineering and Technology (IET) (2022) The IET skills and demand in industry 2021 survey. [PDF] IET. Available at: www.theiet.org/media/9234/2021-skills-survey.pdf

automation risk, grouped into the quartiles of engineering occupations at least (group 1) to greatest (group 4) risk of displacement.

The colours in the table – in shades from white to blue – reflect rankings of prevalence for each of those skills. As a result, skills shaded darker blue are the most prevalent, while those which are white are amongst the least prevalent. By reading this heat map against the automation risk categoris\ations, we can see the scale of potential displacement, on the one hand, or growth, on the other hand, in key engineering roles.

For example, where there are patches of darker blue on the right hand side of the table, this indicates roles that are currently very prominent but at high risk of displacement. Where there are patches of darker blue on the left hand side of the table, this indicates roles that are important now and likely to persist into the future.

Where skills are prevalent across automation quartiles, we suggest that these core skills might underpin a pathway from more to less at-risk roles, so long as they are complemented with upskilling in other relevant skills.

This analysis helps to identify 1) the skills and roles which are most vulnerable to displacement on a larger scale, and therefore the groups most in need of upskilling and security, and 2) the skills and roles that are in demand and unlikely to be displaced by automation, making these a sound investment for employers and the overall sector in future.

Figure 2.2: Heat map of technical engineering skill importance by automation risk quartile

Skill	1 (lowest risk quartile)	2	3	4 (highest risk quartile)
Monitoring, inspecting and testing equipment, systems and products				
Analysing and evaluating information and data				
Interpreting technical documentation and diagrams				
Conducting investigations				
Documenting technical designs, procedures, problems or activities				
Designing systems and products				
Technical or academic writing				
Designing industrial materials, systems or products				
Creating visual displays and decorations				
Monitoring developments in area of expertise				
Evaluating systems, programmes, equipment and products				
Designing electrical or electronic systems or equipment				

Digital skills

- **In older engineering skills frameworks, it is striking how little digital skills are mentioned.**
- **Core digital skills include digital design, digital manufacturing and a range of data-related skills, including data management and analysis.**
- **Currently, most of these skills appear to be more important for occupations at a lower risk of automation.**

Digital skills require some specialist knowledge synonymous with technical capabilities, described above. However, it is possible to draw a distinction between the two. Digital skills refer to an ability to use devices, applications or networks to deliver an outcome, rather than the underlying understanding of the outcome or mechanisms involved: knowing how to use a design programme to draw plans to build a bridge requires digital competency, but being able to design the bridge and understand the underlying physics is a technical skill.

Interestingly, in older engineering skills frameworks like UK-SPEC, there is a striking lack of digital skills mentioned.[80.] By contrast, O*NET highlights digital design software – AutoCAD Civil 3D – as a 'hot technology' for civil engineering[81.] as well as 'computers and electronics' under the 'knowledge' section. SkillsFuture Singapore puts digital literacy and computational thinking under its 'generic skills and competencies' section, as well as more specific skills like '3D modelling' or 'artificial intelligence application'.[82.]

Skills frameworks with a dedicated digital focus, like ManpowerGroup/DMDII's digital manufacturing & design jobs roles taxonomy,[83.] refer to a more delineated range of skills including digital design (the presentation of information via digital means[84.]), digital manufacturing (the use of computer programmes to create product and manufacturing definitions simultaneously[85.]) and a range of skills around data management (eg data continuity, data recovery and data science and management). The National Digital Twin programme's Skills and Competency Framework highlights some of the same capability areas such as data modelling, data fundamentals and analytics and intelligence.[86.]

While computer programming is not often considered an engineering skill, our analysis ranks this skill top in terms of importance given the high number of workers employed as computer programmers and in other related IT roles. The ESCO data also highlights the importance of designing digital systems, using computer aided design (CAD) and several skills relating to digital data management and analysis. As above, many of these skills are involved in occupations that are less at risk of automation. However, it should be noted that the ability to use digital skills to control machinery appears to be important for those in the highest risk quartiles, making broader digital skills a potentially worthwhile investment for employers and employees in those occupations.

A 2018 study by the Construction Industry Training Board (CITB) sheds additional light on this. It suggested that – in construction - people starting to implement technological solutions were typically site managers and engineers. Technologies such as digital tablets

80 Engineering Council (2014) UK-SPEC: UK standard for professional engineering competence (third edition). [PDF] Engineering Council. Available at: www.engc.org.uk/engcdocuments/internet/Website/UK-SPEC%20third%20edition%20(1).pdf
81 O*NET (nd) Civil engineers. [online] Available at: www.onetonline.org/link/summary/17-2051.00
82 SkillsFuture (2023) Op cit.
83 Antonucci, L, et al (2019) Digital manufacturing & design job roles taxonomy [PDF] ManpowerGroup, DMDII. Available at: www.mxdusa.org/app/uploads/2019/11/DMD-Job-Role-Taxonomy.pdf
84 Hannah, J (2021) What is digital design? A comprehensive guide [online] Available at: www.careerfoundry.com/en/blog/ui-design/digital-design-guide/#what-is-digital-design [Accessed 2023].
85 Siemens (nd) Digital Manufacturing. [online] Available at: www.plm.automation.siemens.com/global/en/our-story/glossary/digital-manufacturing/13157 [Accessed 2023].
86 National Digital Twin Programme (2021) Skills and competency framework: Supporting the development of the information management framework (IMF) and the national digital twin. [PDF] National Digital Twin Programme. Available at: www.cdbb.cam.ac.uk/files/010321cdbb_skills_capability_framework_vfinal.pdf

offered more efficient ways of working for supervisors. However, in most cases, these technological adoptions did not yet affect the daily tasks of labourers.[87] This will likely change in the future as more widespread adoption takes hold. As one stakeholder we interviewed told us: "we need to realise that everyone needs a basic level of understanding of the technology" to avoid "creating islands of innovation but instead bring in the whole community".

Figure 2.3: Heat map of digital skill importance by automation risk quartile

Skill	1 (low-est risk quar-tile)	2	3	4 (high-est risk quar-tile)
Programming computer systems				
Managing and analysing digital data				
Designing ICT systems or applications				
Using computer aided design and drawing tools				
Gathering information from physical or electronic sources				
Accessing and analysing digital data				
Using digital tools to control machinery				
Setting up computer systems				
Managing information				

Safety skills

- **Some existing frameworks note a growing interest in, and importance of, safety skills, with employers anticipating a growing need for 'green' safety skills in particular.**
- **Skills relating to compliance with safety procedures and legal and organisational guidelines appear important across all engineering occupations.**
- **Some safety skills – such as performing risk analysis or developing safety policies - are more important for professionals, managers and technicians. However, operatives on the factory floor or building sites need to play different, but not less important roles, for example in maintaining the safety of systems, monitoring operations and reporting incidents and defects.**

In the skills frameworks we studied, issues of safety and risk appear to be of growing importance. In SkillsFuture Singapore, for example, their top-level 'desired attributes' and 'skills in demand' include 'safety conscious' and 'design for safety' respectively. Safety skills refer to a spectrum including aspects of health and safety, environmental protection and sustainability, cyber security, and compliance with legal and regulatory requirements.

While the IET's research suggests that 81 percent of employers think they'll need to upskill their workforce in green skills,[88] the level of detail on the capabilities needed to manage environmental impacts is limited within the frameworks we studied. SkillsFuture Singapore includes 'sustainable engineering' as a technical skill and 'implement sustainable design' is included as a critical work function for various roles, while the Australian government's graduate Capability Framework embeds 'assessment of impact, risk and sustainability' and 'environmental planning and management' within its process capabilities. Overall, though, this may suggest more needs to be done to fully map out – and build the capabilities required for the transition to net zero and beyond.

The ESCO analysis further highlights the centrality of safety skills to the future of engineering. Skills relating to compliance with safety procedures and legal and organisational guidelines are important across all engineering occupations. While skills relating to performing risk analysis or developing safety policies and procedures are more important for occupations with a lower automation risk such as professionals, managers and technicians. Interestingly, our analysis suggests that operatives on the factory floor or building sites play an important role in maintaining the safety of systems and processes through monitoring operations and reporting incidents and defects.

Figure 2.4: Heat map of safety skill importance across automation risk quartile

Skill	1 (low-est risk quar-tile)	2	3	4 (high-est risk quar-tile)
Complying with health and safety procedures				
Complying with legal and organisational guidelines				
Developing operational policies and procedures				
Performing risk analysis and management				
Complying with environmental protection laws and standards				
Monitoring safety or security				
Training on operational procedures				
Providing information to the public and clients				
Maintaining and enforcing physical security				
Reporting incidents and defects				

Transferable skills

- **In our analysis there are three different types of transferable skills: interpersonal skills, creative problem solving and business and organisational management skills.**
- **The majority of interpersonal skills, along with creative problem solving skills, are important across engineering roles irrespective of automation risk.**
- **While business and organisational management skills are more immediately associated with (less at-risk) managerial positions, related skills are important for medium-risk occupations, such as estimating resource needs, allocating physical resources, purchasing goods and services, and managing contracts.**

The skills frameworks we studied referred to a wide range of transferable skills, all categorised slightly differently. For example, three of the UK-SPEC's five competency areas refer to transferable skills: responsibility, management or leadership; communication and inter-personal skills; and professional commitment. The Royal Academy of Engineering's critical capabilities framework also places a lot of emphasis on transferability, with a nested framework that starts with 'core engineering mind' at its centre ('making things that work and making things work better'), then 'engineering habits of mind' (creative problem solving, problem finding, adapting) and followed by 'learning habits of mind' (collaboration, resilience, open-mindedness). Other skills frameworks refer to teamwork, creative thinking, project development and being a team player (SkillsFuture

87 CITB (2018) Unlocking construction's digital future: a skills plan for industry. [PDF] CITB. Available at: www.citb.co.uk/media/0pkin1nj/citb_constructions_digital_future_report_oct2018.pdf
88 The Institution of Engineering and Technology (IET) (2022) Op cit.

Singapore), active listening, complex problem solving, critical thinking (O*NET), or stakeholder management, effective communication, winning and delivering projects as key 'generic' capabilities. Our analysis of these and other frameworks suggest these can be broadly categorised as interpersonal skills, creative problem solving and business and organisational management skills. That these are felt to be important for engineering employers is reflected in the IET skills and demand in industry survey, which found that the soft skills employers most frequently felt were lacking include team working (49 percent), time management and prioritisation (43 percent), leadership and management skills (39 percent) and customer handling skills (31 percent). Other skills which were reasonably big problems (with 20 percent+ reporting) included project management, setting objectives for others and planning resources and training or instructing people.

As in the other skills frameworks, the list of transferable skills in ESCO is extensive. As above, in our analysis we distinguished between three different types of transferable skills: interpersonal skills, creative problem solving and business and organisational management skills. As expected, the majority of interpersonal skills remain important across the different quartiles, with only those relating to supervising, developing professional relationships or advising and consulting not important for the most at-risk quartile. Similarly, while there is only one skill in the ESCO that relates to central aspects of the 'engineering mind', creative problem solving (described in ESCO as 'developing solutions') this is cultivated in all engineering roles, irrespective of their automation risk.

Figure 2.5: Heat map of interpersonal skills importance across automation risk quartile

Skill	1 (lowest risk quartile)	2	3	4 (highest risk quartile)
Presenting general information				
Planning and scheduling events and activities				
Coordinating activities with others				
Leading and motivating				
Advising and consulting				
Developing professional relationships or networks				
Supervising a team or group				

Business and organisational management skills, unlike interpersonal skills or creative problem solving, are not typically considered as 'soft' or 'non-cognitive' skills but are transferable in the sense that they are needed to work in many different types of jobs or businesses outside of engineering contexts. Looking at our analysis in Figure 2.6, some of these skills are also transferable across engineering occupations, for example directing and monitoring operational activities, or maintaining operational records. Others relating to organisational strategy, developing business plans and managing finances are typically more important for managerial roles in the lowest automation risk quartile. This said, many related skills are important for occupations in the medium-low and medium-high quartiles, typically technicians or tradespeople: for example, estimating resource needs, allocating physical resources, purchasing goods and services and managing contracts. As Chapter 1 highlights, managerial roles in engineering are experiencing significant growth and this may represent an opportunity for employers to look at their internal workforce and network of contractors in order to address emerging skills shortages.

Figure 2.6: Heat map of business and organisational management skills across automation risk quartiles

Skill	1 (lowest risk quartile)	2	3	4 (highest risk quartile)
Directing operational activities				
Maintaining operational records				
Developing objectives and strategies				
Analysing business operations				
Estimating resource needs				
Allocating and controlling physical resources				
Monitoring operational activities				
Purchasing goods or services				
Preparing financial documents, records, reports, or budgets				
Performing general clerical and administrative tasks				
Negotiating and managing contracts and agreements				
Analysing financial and economic data				
Developing financial, business or marketing plans				
Managing budgets or finances				

CHAPTER 3: SKILLS NEEDED FOR THE SAFE ADOPTION OF EMERGING TECHNOLOGIES

Skills needed for the safe adoption of emerging technologies

The first part of this chapter presents the safety challenges and opportunities that are brought about by the exemplar emerging technologies. We look at worker safety, with opportunities in terms of accident prevention and hazard detection, and challenges in terms of workplace monitoring and privacy.

The second part of the chapter then identifies the current and future skills that have been identified through the horizon scan, literature review, interviews and other stakeholder engagement as increasing in importance due to those emerging technologies. In line with the categories we outlined in the second chapter, we will look at the way emerging technologies are shaping the demand for **technical, digital, safety** (including green safety) and **transferrable skills.**

Our findings are based on a horizon scan of the ways in which our exemplar technologies are impacting on engineering roles and safety, and a series of workshops with industry professionals to explore evolving skills needs.

Key points

The exemplar technologies we have considered present both challenges and opportunities within the world of engineering.

We find, with regards to worker safety, that:

- **Emerging technologies offer new opportunities with regards to hazard protection, and by tracking worker wellbeing in hazardous environments. There are, however, concerns that these tracking capabilities could be used to police workers if appropriate regulation is not forthcoming.**
- **Predictive maintenance of machinery promises benefits both for employers – in reduced downtime and cost – and for workers – by reducing the risk of accidents.**
- **Robotic exoskeletons and RAS can protect against physical overexertion and fatigue, while remote, autonomous surveillance and inspection can remove the requirement for workers to enter hazardous environments. However, unless suitably equipped, robots may not sense humans and thus pose a potential risk to their safety.**
- **Hydrogen is non-toxic; however, it is odourless, disperses quickly, and it can cause fires at a low ignition point, so careful monitoring and threat detection are important.**

With regards to environmental safety, we find that:

- **The coming together of IoT and RAS promises efficiencies and better use of resources for a number of production processes, as well as in distribution and logistics, reducing energy use and carbon output.**

- **However, rebound or replacement effects have been noted, whereby greater efficiency leads to reduced cost, which in turn causes consumption to spike. The net result might be increased, rather than decreased, resource use and carbon output.**
- **Furthermore, the act of digitising and automating production and distribution processes can often be carbon-intensive in itself, and the hardware that this relies on tend to have relatively short lifespans, leading to increased e-waste.**
- **Hydrogen fuel presents a mixed picture. At present, hydrogen production is still a high-emitting process, and it cannot easily or comprehensively supplant fossil fuels. Nevertheless, hydrogen presents promise as a potential store of energy derived from other clean energy sources, better able to respond to short term fluctuations in supply and demand.**

And finally, concerning cyber security:

- **IoT and RAS open up a number of vulnerabilities within cyber security. Greater connectedness to the internet logically increases the attack surface that hackers can target, and this risk is compounded by a lack of standardisation and regulation.**
- **Similarly, the simplification and acceleration of robotics development has created new weaknesses.**

The ways these emerging technologies impact the safety profiles of engineering also have an influence on the skills that will be needed to safely adopt them. From our horizon scan and workshops with industry experts, we have identified the following key skills as being central to the safe adoption of emerging technologies:

Skills category	Summary of new skills needed for the safe adoption of emerging technologies
Technical: skills relating directly to specialist engineering knowledge and capabilities.	• Interdisciplinary approaches to work, especially among team leaders • Cross-cutting knowledge of programming languages • Specialist knowledge and tools relating to data analysis and data management • Specialist technical knowledge relating to specific forms of technology • Specific design skills such as computation geometry and circuit design
Digital: skills relating to digital knowledge and capabilities.	• Knowledge of specific programming languages and proprietary languages • Design skills requiring specialist knowledge of digital tools • Machine learning and deep learning skills to ensure safety and security
Safety: skills relating directly to safety knowledge and capabilities.	• Safety requirements will be closely linked to digital skills (above) • Competency in real-world testing and experimentation, including ethical hacking to stress-test vulnerabilities • The ability to conduct risk assessments and skills in risk management, as well as more specialist knowledge in relation to specific technologies • Knowledge of how to safely intervene in human-machine interactions • Specialist knowledge with regards to regulatory compliance, certification and documentation processes
Transferable: general skills that could be adapted to other professional contexts, engineering or otherwise.	• Systems thinking, analysis and evaluation to integrate new technologies into the industry • Entrepreneurial skills to spot value-adding opportunities • Knowledge of and ability to anticipate sustainability and safety implications • A continued (and currently under-served) need for practical skills (such as assembly, welding and soldering)

3.1 Safety challenges and opportunities

Safety profiles change, and the risks and opportunities to increase safety that engineers need to be prepared for are constantly changing. Some of the challenges and opportunities in terms of the different types of safety we look at might have common themes across different emerging technologies. Considering the three exemplar technologies – Internet of Things, robotics and autonomous systems, and hydrogen and new fuels – we have found both distinct and common challenges and opportunities that might intersect or be specific to each.

Worker safety

Emerging technologies are presenting specific opportunities and challenges for worker safety in terms of workplace safety, health and wellbeing.

Hazard detection

One key way in which new technologies are increasing worker safety is through increased accident prevention through hazard detection. IoT specifically can help protect workers who are more likely to work in hazardous environments. It offers unparalleled levels of granularity when it comes to monitoring and controlling an environment. "Sensors installed across locations can also enable pre-emptive intervention in case of accidents and emergencies".[89.]

Sensors that some industrial companies embed in employee uniforms and helmets can detect hazardous conditions such as toxic gases, or warn of over-exertion (based, for example on employee's heartbeat).[90.] SmartCap is a wearable device that tracks brain waves using electroencephalography (EEG) to monitor worker fatigue. It is used in construction, manufacturing, but also to track 'microsleeps' that might happen to drivers in long-haul journeys and that might pose fatal safety risks.[91.] Other IoT devices in the workplace were used during the Covid-19 pandemic to monitor the number of workers on a site and to trace contact between workers who might have been infected.

Surveillance risks

IIoT applications can be used to increase the physical safety and wellbeing of workers, but they might represent a double-edged sword. Such applications could be used to monitor employees in ways for which the technology was not intended.[92.]

Geofencing is a specific feature of geolocation that triggers a response when a device or piece of equipment crosses a virtual 'fence', defined by an administrator.[93.] Geofencing shows up as a feature, with a combination of IoT and GPS tracking in the context of fleet management, as in the case of OverWheels, a fleet management solution used in Singapore by Overdrive IoT.[94.] Real time location tracking can alert personnel in the event they enter high risk areas. However, there are concerns that it might also be used to monitor and police employees' movement more generally.[95.]

This presents a risk profile for workers' privacy, not only because of increased liability of cyber attacks, but also by improper use of worker data by employers. There is a clear tension between the safety increases that might come from tools such as SmartCap, but that might come with an untenable level of granularity of data, including brain wave data.

89 Bardiya, A (2021) Why IoT is key to maintaining industrial workers' safety. [online] Available at: www.tatacommunications.com/blog/2021/03/why-iot-is-key-to-maintaining-industrial-workers-safety/ [Accessed 2023].
90 Lyon, C (2016) The unblinking eye: employee monitoring in the IoT era. [online] Available at: www.informationweek.com/big-data/the-unblinking-eye-employee-monitoring-in-the-iot-era [Accessed 2023].
91 SmartCap (nd) Wearable technology that eliminates microsleeps Available at: www.smartcaptech.com/#:~:text=eliminates%20microsleeps.,helping%20operators%20manage%20their%20alertness [Accessed 2023].
92 Lyon, C (2016) Op cit.
93 Overdrive (nd) A simple guide to geofencing and its various applications. [online] Available at: www.overdriveiot.com/a-simple-guide-to-geofencing-and-its-various-applications/ [Accessed 2023].
94 Overdrive (nd) Seamless solution for effective fleet monitoring. [online] Available at: www.overdriveiot.com/a-simple-guide-to-geofencing-and-its-various-applications/ [Accessed 2023]; overdriveiot.com/products/overwheels/
95 Overdrive (nd) A simple guide to geofencing and its various applications. Op cit.

One clear requirement is introducing clearer and more stringent regulation on worker data. Previous RSA research called for the establishment of regulation akin to a 'GDPR for workers' and stronger democratic data, especially in the workplace.[96.]

Predictive maintenance

Emerging technologies can help decrease the incidence of accidents in a variety of ways. One such way is through predictive maintenance. This refers to the use of "real-time IoT sensor data and AI techniques to determine when maintenance should be performed on specific equipment".[97.] This is highly valuable as it can help reduce downtime, increase efficiencies and reduce cost, and can also have a positive impact on accident prevention.

RAS can also operate maintenance and disposal in different production environments. One example is Toshiba's Little Sunfish robot which was employed by Toshiba and Tokyo Electric Power Company (TEPCO) to map the area in the Fukushima power plant, in order to find missing radioactive fuel.[98.]

Human-machine interactions

RAS can decrease the incidence of workplace injuries by making up robotic exoskeletons. Assistive exoskeletons, including EksoWorks by Ford, and the more advanced Guardian XO robot by Sarcos Robotics, can multiply the ability to lift weights by a factor of 20.[99.] German Bionic recently released the fifth generation of AI-powered exoskeleton Cray X, which is already in use at BMW, IKEA and DPD, a French delivery service.[100.]

Industrial exoskeletons have shown promise in reducing the risk of musculoskeletal injuries in the workplace.[101.] RAS more generally can minimise injuries caused by workers' fatigue. For instance, robots in the warehouse can be tasked with reaching precarious or high-up objects to minimise fall hazards for traditional workers, and can remove the need for workers to operate aerial lift equipment.[102.]

However, risks might increase precisely due to the nature of human-robot interactions. One reason is that older generations of cobots cannot often see or hear the presence of humans.[103.] For this reason, many industrial robots need to be kept separate from human workers on the factory floor, for example through being encased in protective cages.

In 2015 a warehouse employee at a bottled water company was killed by the forks on a robotic, driverless forklift known as an LGV (laser-guided vehicle), which is equipped with safety sensors designed to detect objects in its path. The sensor's alarm was triggered by a piece of plastic wrap underneath the forks. The victim did not initiate the emergency stop, which meant that when it resumed its automated functions they were crushed by the forklift.[104.]

The other way in which human-machine interactions can present higher risk profiles is the blurring of the focus of decision-making in emergency situations. Operators may make a poor decision when a RAS unexpectedly hands over control (unless they have

96 Lockey, A, Wallace-Stephens, F (2020) A new blueprint for good work. [PDF] RSA. Available at: www.thersa.org/globalassets/reports/2020/a-new-blueprint-for-good-work.pdf
97 Lockey, A, Wallace-Stephens, F (2020) Ibid.
98 Beiser, V (2018) The robot assault on Fukushima. [online] Available at: www.wired.com/story/fukushima-robot-cleanup/ [Accessed 2023].
99 Innovation (nd) This robotic exoskeleton allows you to lift 200 pounds effortlessly. [online] Available at: www.imnovation-hub.com/construction/robotic-exoskeleton-allows-lift-pounds-effortlessly/?_adin=02021864894 [Accessed 2023].
100 Koetsier, J (2021) BMW, IKEA using AI-powered exoskeleton that adds 66 pounds of lift force. [online] Available at: www.forbes.com/sites/johnkoetsier/2021/12/27/bmw-ikea-using-ai-powered-exoskeleton-that-adds-66-pounds-of-lift-force/?sh=e8865bb45fa8 [Accessed 2023].
101 Texas A&M University (2021) Increased cognitive demands offset low-back exoskeleton advantages, research finds. [online] Available at: www.sciencedaily.com/releases/2021/10/211028120351.htm [Accessed 2023].
102 Gould, G (2019) The impact of robotics on safety and health. [online] Available at: www.wolterskluwer.com/en/expert-insights/the-impact-of-robotics-on-safety-and-health [Accessed 2023].
103 LaRanger, R (2020) What's driving the adoption of robots in industry? [online] Available at: www.prescouter.com/2020/01/whats-driving-the-adoption-of-robots-in-industry/ [Accessed 2023].
104 Gould, G (2019) Op cit.

maintained thorough situational awareness). At the same time, operators with poor situational awareness might not trust a RAS and override it.

Further, recent studies suggest that there might be new, non-physical risks stemming from the interaction between human and machine. Where there are low-back exoskeleton advantages, a study by Texas A&M University found they might be offset by increased cognitive demands on workers.[105.] There is a neurocognitive 'cost' of wearing an exoskeleton which impacts the wearer's motor and cognitive capabilities and may cancel out the benefits of the technology entirely.

Tech removing humans from hazardous environment

RAS are contributing to the safety of workers by removing the need for a human to be physically present in a hazardous environment. In the oil and gas industry, Spot the robotic 'dog' from Boston Dynamics has been used in offshore locations to avoid placing humans in potentially hazardous situations. Spot was used in the Norwegian sea by Cognite and Aker BP for autonomous data collection and sharing and to generate automatic reports.[106.] In this case, RAS and digital twins were employed at the same time. Spot was also used in the deep water environment in the Gulf of Mexico to monitor methane, identify potential leaks and read gauges in hard-to-reach locations. In Malaysia, national oil company Petronas partnered with Waygate Technologies to develop and market ANYmal, a surface operation robot that allows for autonomous surveillance and inspection in hazardous and hard-to-reach environments.[107.] The University of Bristol Hot Robotics facility develops RAS with the aim of keeping humans safe by enabling remote access to dangerous environments.[108.]

Hydrogen ignition

Hydrogen presents risks to people that come into contact with it. Hydrogen is relatively lighter than other fuels, which means that it can more easily disperse in the atmosphere.[109.] This increases risks of leakage, especially as it also may weaken steel pipes it is transported in. This is a key risk as it also has among the lowest minimum ignition energy amongst known substances, which presents an increased risk of ignition and explosion.[110.] It is also odourless, and hydrogen flames are nearly invisible, requiring additional testing methods to monitor the presence of flames and leakages.

However, hydrogen is non-toxic, which means that leaks and spills do not harm human health unless they are caused to ignite. Also, its lightness means that it is quicker to disperse in the air and less likely to ignite at ground level.[111.] It has lower radiant heat which means that even when ignited there is a lower risk of secondary fires as the air around the hydrogen flame is lower heat than a gasoline flame.[112.]

Safety for the environment

Emerging technologies present both opportunities and challenges with respect to the safety of the environment.

One example of the environmental safety benefits of emerging technologies is the promise of more efficient resource use, reducing in turn the amount of energy and

105 Texas A&M University (2021) Op cit.
106 Beaubouef, B (2021) Offshore industry embraces robotic technology. [online] Available at: www.offshore-mag.com/production/article/14206250/offshore-oil-and-gas-industry-embraces-robotic-technology [Accessed 2023].
107 PETRONAS (2022) PETRONAS and waygate technologies to commercialise co-developed robotic inspection solution. [online] Available at: www.petronas.com/media/media-releases/petronas-and-waygate-technologies-commercialise-co-developed-robotic-0 [Accessed 2023].
108 University of Bristol (2022) Recharge the batteries at Bristol's state-of-the-art robot expo at Millennium Square. [online] Available at: www.bristol.ac.uk/news/2022/april/robot-expo.html [Accessed 2023].
109 Cho, R (2021) Op cit.
110 Pacific Northwest National Laboratory (PNNL) (2021) Hydrogen incident examples. [PDF] PNNL. Available at: www.h2tools.org/sites/default/files/Hydrogen_Incident_Examples.pdf
111 Tae, C (2021) Hydrogen safety: let's clear the air. [online] Available at: www.nrdc.org/experts/christian-tae/hydrogen-safety-lets-clear-air [Accessed 2023].
112 Tae, C (2021) Ibid.

carbon that come from operations. The coming together of IoT and RAS also provides efficiencies and better use of resources for many production processes.[113.] What is commonly known as Industry 4.0 or the Fourth Industrial Revolution (4IR) refers to a case in which different digitally-enabled technologies are integrated and combined into manufacturing processes, to "connect, integrate and optimise production processes, factories and entire value chains".[114.] This requires advances in digital technologies, data and applications. Some of the technologies these processes centre around are Internet of Things, big data, cloud computing, machine learning, artificial intelligence, 3D printing.[115.]

IoT can support firms to make more efficient choices and can support environmental risk management. A key feature is a range of tools that help with asset-tracking that can support a more efficient transportation and use of materials and equipment, reducing environmental impacts. A range of IoT-based asset-tracking tools include those in the construction sector, such as those from Atmel, which uses GPS tracking on construction equipment and materials, and Ayantra Asset Management, which monitors lifts and other heavyweight equipment.[116.]

Fleet management can also benefit from asset-tracking and can reduce energy and resources used. Fleet management is particularly useful in companies that have large fleets of vehicles, including in the automotive sector. In this case, its benefits include supporting driver behaviour monitoring, fuel monitoring and predictive fleet maintenance.[117.] An emerging possibility in this field is the use of satellite technology to increase connection at a reasonable price.[118.]

IoT-based route optimisation is rising rapidly, with 57 percent of respondents to the Inmarsat research operating or trialling it, rising to 66 percent excluding the fishing industry.[119.] Logistics companies can shorten delivery routes through intelligent route planning, with environmental benefits in the form of reduced carbon output.[120.] Singapore-based shipping software provider iO3 is working on improving weather and routing intelligence capabilities in iO3's V.IoT shipboard data aggregation system.[121.]

However, efficiencies in production driven by IoT and RAS can both create what are commonly referred to as rebound or replacement effects. This refers to an increase in consumption because of lowered cost due to increased efficiency, ultimately increasing emissions and resource use.[122.] Goods can become goods of mass consumption, that might have not been before, due to the decreased cost to both producers and consumers, and thus the number of items produced grows. For this reason, technology advancements need to be accompanied by the right policies and systemic planning.[123.]

Companies in the packaging industry are also starting to use IoT to enhance the efficiency of their operations. Tetra Pak, Amcor and Berry Global, for example, are using IoT to

113 Javaid, M, et al (2021) Substantial capabilities of robotics in enhancing industry 4.0 implementation. [PDF] Cognitive Robotics. Available at: www.sciencedirect.com/science/article/pii/S2667241321000057
114 Leal-Ayala, D et al (2019) OK computer? [PDF] Policy Links. Available at: www.ciip.group.cam.ac.uk/reports-and-articles/ok-computer-safety-and-security-dimensions-industr/download/OK_Computer.pdf
115 Leal-Ayala, D et al (2019) OK computer? Ibid.
116 Digiteum team (2020) How IoT can improve the construction industry [online] Available at: www.digiteum.com/iot-construction-industry/ [Accessed 2023].
117 UpKeep (nd) What are the most common use cases for sensors and IoT in Fleet Management? [online] Available at: www.upkeep.com/learning/sensors-and-iot-in-fleet-management [Accessed 2023].
118 Wegner, P (2021) The top 10 IoT use cases. [online] Available at: www.iot-analytics.com/top-10-iot-use-cases/ [Accessed 2023].
119 Inmarsat (2018) Industrial IoT on land and at sea: maritime. [PDF] Inmarsat. Available at: www.inmarsat.com/content/dam/inmarsat/corporate/documents/maritime/insights/Inmarsat_IIoT_on_land_and_at_sea_Maritime.PDF
120 Leonards, A (2020) Is IoT a silver bullet for climate change? [online] Available at: www.raconteur.net/technology/internet-of-things/industrial-iot-climate-change/ [Accessed 2023].
121 O'Dwyer, R (2022) iO3 to integrate DTN weather and route data into maritime applications [online] Available at: www.smartmaritimenetwork.com/2022/07/26/io3-to-integrate-dtn-weather-and-route-data-into-maritime-applications/ [Accessed 2023].
122 Wright, L (2019) If robots take our jobs, what will it mean for climate change? [online] Available at: www.theconversation.com/if-robots-take-our-jobs-what-will-it-mean-for-climate-change-123507 [Accessed 2023].
123 Leonards, A (2020) Op cit.

help deliver ESG targets, including through using Water Flow Intelligence.[124.]

We note two further environmental challenges with regards to RAS and IoT. The first relates to the added energy and electricity required for operations to be digitised and automated rather than carried out by humans. The other is concerned with waste, or what is known as e-waste or ICT waste. IoT sensors and actuators can have a short lifespan which leads to increased waste in the environment.[125.] Smart cities have concerns surrounding ICT waste management, energy management and emission management.[126.]

Maritime engineering

In the maritime sector, the growing prevalence of Internet of Things, alongside big data and AI, are necessitating renewed assessments of cyber security provisions. A recent systematic review of cyber security in the maritime industry found that "the reliance on the internet, operating with unprotected computers, and the fact that crews do not receive appropriate security training increase further the probability of a successful cyber breach".[127.]

According to recent research by the Inmarsat Research Programme, IoT is seen as a 'straightforward way of getting its house in order' in response to riding environmental concerns. Decarbonising maritime shipping is key as it accounts for 3 percent of all global emissions, but could rise to 10 percent if plans to decarbonise are not fast enough.[128.] In this context, Maersk, aims to create the world's first carbon-neutral liner vessel fuelled by methanol in 2023, earlier than the original 2030 plan. Iberdrola, the Spanish energy giant, is partnering with ABEL Energy to develop a £1.7bn project in Tasmania to create green fuel for the shipping industry by making green methanol from green hydrogen,[129.] and Amazon, Ikea and Unilever have pledged to only move cargo ships using zero carbon fuels by 2040.[130.]

Hydrogen fuels offer a number of opportunities in engineering but present some complicated and technical challenges to resolve over the medium to long term.

Firstly, it merits attention that currently, as most of the world's hydrogen is grey hydrogen, it is still high-emitting, producing 830m metric tons of CO2 emissions per year.[131.] While the potential use cases for green hydrogen are numerous, for positive safety implications for the environment to be achieved, use needs to be well researched.

There is a worrying trend of assuming clean hydrogen is the solution to most operations where use of energy is needed. That is not the case, as research shows that hydrogen use should be focused on use cases where it is difficult to use cheaper, cleaner technologies and where clean hydrogen can use existing infrastructure.[132.] It is meant to support decarbonisation of 'hard to abate' heavy industries like long-haul transport, chemicals,

124 Ellington, R (2022) How the Internet of Things is revolutionising the packaging industry. [online] Available at: www.packaging-gateway.com/analysis/how-iot-is-revolutionising-the-packaging-industry/ [Accessed 2023].
125 Razip, MM, et al (2022) The development of sustainable IoT E-waste management guideline for households [PDF] Chemosphere. Available at: www.sciencedirect.com/science/article/abs/pii/S0045653522012607
126 Dwivedi, YK et al (2022) Climate change and COP26: Are digital technologies and information management part of the problem or the solution? An editorial reflection and call to action. [PDF] International Journal of Information Management. Available at: www.sciencedirect.com/science/article/pii/S0268401221001493
127 Ben Farah, MA, et al (2022) Cyber security in the maritime industry: a systemic survey of recent advances and future trends. [PDF] MDPI. Available at: www.open-access.bcu.ac.uk/12982/1/information-13-00022%20%284%29.pdf
128 Thomas, D (2021) Op cit.
129 Macdonald-Smith, A (2022) Spanish giant joins $1.7b Tassie hydrogen project. [online] Available at: www.afr.com/companies/energy/spanish-giant-joins-1-7b-tassie-hydrogen-project-20221219-p5c7fk [Accessed 2023].
130 Dempsey, H & Lee, D (2021) 'Amazon, Ikea and Unilever commit to zero-emission shipping by 2040', The Financial Times. [online] Available at: www.ft.com/content/850eee4b-2c2d-4186-99d7-fdbe8131ddd0 [Accessed 2023]
131 Cho, R (2021) Op cit.
132 Hegnsholt, E et al (2019) Op cit.

aviation, and iron and steel.[133] In terms of steel, Ørsted, a Danish multinational and largest offshore wind power company, is cooperating with South Korean steelmaker POSCO on a feasibility study for the production of green hydrogen to prepare for the supply of hydrogen steel.[134]

One environmental benefit is related to its promise as a solution for storing energy from more variable clean energy sources such as photovoltaics and wind, which can help overcome the mismatch between short-term supply and demand. Further, recent research shows positive strides in using seawater for green hydrogen, which could greatly improve the chances of using offshore wind to power seawater electrolysers in a sustainable way.[135] Similar efforts are behind Gigastack, a UK flagship renewable hydrogen project that aims to provide "world-leading supply chain and highly skilled jobs across the sector".[136]

A key benefit of hydrogen is the potential to use existing oil and gas pipelines. Proponents state that, while currently it is transported through dedicated pipelines, in lower concentrations it can be transported in existing natural gas pipelines. However, as mentioned, pure hydrogen transportation would require major restructuring of the existing pipeline to guarantee safety.[137]

More generally, interviewees and workshop participants highlighted that often, the rush to adopt new technologies can create unnecessary use of other resources. Urgency and a lack of critical understanding of benefits and implications of emerging tech also can lead to inefficient decision-making. One example that workshop attendants highlighted is how an excessive focus on hydrogen can deprioritise more research and funding for renewables, which are more appropriate in some contexts. Further, it can divert conversations from wider systemic solutions – it was noted in our industry workshops that public transport was missing from these conversations, and that when considering decarbonisation there was a lack of consideration for nature-based solutions.

Cyber security

The emerging technologies, especially IoT and RAS, have implications on the severity of risks to cyber security.[138]

Previous research conducted for the Lloyd's Register Foundation predicts that the risk of deliberate attacks will increase as the Industrial IoT expands.[139] Generally, the use of IoT, and the connectedness of devices to the internet – has increased the attack surface.[140] There have been increased numbers of malware attacks. In this sense, the connectedness of IoT to the internet, which in this case is the 'threat vector', represents a constant risk.[141] The related tech also increases the risks of attack, including enabling tech like software-defined networking (SDN), cloud computing and fog computing.[142]

An absence of standardisation makes it significantly harder to allow machine-to-machine communications without raising risks.[143] Further, because of a laxness in regulation, many IoT device manufacturers and service providers are failing to implement common security measures in their products. A team of researchers at Microsoft and the University of

133 International Energy Agency (IEA) (2019) Op cit.
134 Toyama, N (2022) Op cit.
135 Hebden, K (2023) Scientists produce green hydrogen from seawater, The Chemical Engineer. Available at: www.thechemicalengineer.com/news/scientists-produce-green-hydrogen-from-seawater/ [Accessed 2023]
136 Gigastack (nd). Gigastack Available at: gigastack.co.uk/ [Accessed 2023]
137 Cho, R (2021) Op cit.
138 Creese, S et al (2020) Op cit.
139 Creese, S et al (2020) Ibid.
140 Creese, S et al (2020) Ibid.
141 Meola, A (2016) Researchers discover multiple vulnerabilities in Samsung's SmartThings platform. [PDF] Insider. Available at: www.businessinsider.com/samsung-smartthings-platform-iot-security-issues-internet-of-things-2016-5?r=US&IR=T [Accessed 2023].
142 Hussain, F, Hussain, R, Hassan, SA, and Hossain E (2019) Machine learning in IoT security:current solutions and future challenges. [PDF] arXiv. Available at: www.arxiv.org/pdf/1904.05735.pdf
143 Radanliev, P, De Roure, DC, Nurse, JRC et al (2020) Future developments in standardisation of cyber risk in the Internet of Things (IoT). SN Appl. Sci. 2, 169.

Michigan found multiple vulnerabilities in the security of Samsung's SmartThings smart home platform.[144] Cases like these clearly underline the increased risk that might come to users especially as the connection between physical and cyber security risks deepens.

This has key implications for the use of RAS as well. Some risks stem from vulnerabilities inherent in the way RAS is built. Alias Robotics discovered numerous and dangerous vulnerabilities in the Robot Operating System (ROS) communications. It discovered around 15 common vulnerabilities present in almost 650 different devices.[145] Further, while robotic development frameworks have simplified and sped up the development of robotics applications, and reduced the costs of new developments, they have brought security flaws to the robotics system.[146] Embedding cyber security into RAS is still a topic in its infancy, but some commercially available robots are starting to be equipped for cyber safety, including through the better use of encryption.

3.2 Skills for the safe adoption of emerging technologies

We now turn our attention to the skills that will be needed in the world of engineering for the safe adoption of emerging technologies. As in Chapter 2, these are grouped under our framework of technical, digital, safety, and transferable skills. These skills were identified through our horizon scan, existing skills frameworks, and a series of roundtables with industry professionals.

Digital skills

- **Knowledge of specific programming languages (such as Python, JavaScript and C++) will become more important for IoT engineers. With regards to robotics and automation, proprietary languages such as Adeno-associated viruses (AAV) and KUKA Robot Language (KRL) will take on increasing importance.**
- **Design skills will also require specialist knowledge of digital tools.**
- **Machine learning and deep learning skills will be central to ensuring the safety and security of IoT technologies, in contrast with established approaches reliant on cryptography, as will skills and knowledge relating to regulatory compliance.**

One area of skills that will grow in importance due to the introduction of emerging technologies is a wide range of digital skills. The specific skill sets needed will depend on the technology being used.

In terms of programming languages, for example, JavaScript, Python, C++ and more specific languages like Arduino, AngularJS will be the main focus for IoT engineers, compared to, for example, earlier engineers in manufacturing technology, where C dominates.[147] For RAS, Python and C/C++ are seen as the main programming languages used for robotic operating systems. These however need to be augmented with the knowledge and understanding of different proprietary languages that most manufacturers of RAS have developed. These include Rapid from AAV, KUKA Robot Language from KUKA, AS from Kawasaki, and URScript for Universal Robotics.

144 Alias Robotics (2022). "Alias Robotics discovers numerous and dangerous vulnerabilities in the Robot Operating System's (ROS) communications that can have "devastating consequences". Cision PR Newswire Available at: www.prnewswire.com/news-releases/alias-robotics-discovers-numerous-and-dangerous-vulnerabilities-in-the-robot-operating-systems-ros-communications-that-can-have-devastating-consequences-301513741.html [Accessed 2023]
145 Alias Robotics (2022). "Alias Robotics discovers numerous and dangerous vulnerabilities in the Robot Operating System's (ROS) communications that can have "devastating consequences". Cision PR Newswire Available at: www.prnewswire.com/news-releases/alias-robotics-discovers-numerous-and-dangerous-vulnerabilities-in-the-robot-operating-systems-ros-communications-that-can-have-devastating-consequences-301513741.html [Accessed 2023]
146 Martín, F, Soriano, E and Cañas, JM, (2018) Quantitative analysis of security in distributed robotic frameworks. Robotics and Autonomous Systems, 100, pp95-107.
147 Tutorialspoint (nd) Programming Languages for the Internet of Things (IoT). [online] Available at: www.tutorialspoint.com/programming-languages-for-the-internet-of-things-iot [Accessed 2023].

In terms of design, AutoCAD will increase in importance for both IoT systems and RAS. Digital tools for user interface (UI) and user experience (UX) design include Adobe XD, Figma and Sketch.[148] In terms of data analysis, MATLAB is popular for analysing data in the context of robotic engineering and developing control systems.

Specific digital skills will be needed for developing 'safetytech'. These respond to different security concerns raised by emerging technologies. For example, traditional efforts have addressed IoT privacy and security concerns through traditional cryptography; however, due to the amount and heterogeneity of data generated by IoT sensors, this approach has proven lacking. Machine learning and deep learning skills are more appropriate for designing and building more innovative solutions.[149] Specific tools might be used for safety and regulatory compliance for IoT, including Cloudfare's Orbit.[150]

Safety skills

- **Safety requirements appear to be inextricable from digital skills given the central need for a strong security framework.**
- **Competency in conducting real-world testing and experimentation will be vital. This may also include skills in ethical hacking to stress-test technologies' vulnerabilities.**
- **A more formalised package of safety training was suggested by industry professionals, with relevant skills including the ability to conduct risk assessments and skills in risk management. However, within safety compliance, there may be more specialist knowledge to develop in relation to specific technologies.**
- **Good safety procedures will also require experts who can accurately assess whether an autonomous system is functioning as intended, and how to safely intervene in human-machine interactions.**
- **Regulatory compliance will require specialist knowledge with regards to the certification requirements and documentation processes relevant to specific forms of emerging technology.**

Multiple stakeholders in our qualitative enquiry highlighted the safety implications of having the right technical and digital skills. One participant observed that "not every safety specialist understands tech". This becomes an issue for safety because "what you can do [when an emerging technology] is sometimes much deeper than what you can see". These more general digital skills are needed also for building security frameworks. For those tasked with developing the security frameworks for IoT, there is a necessity to be able to carry out real-world experimentation and testing. This means that they must be aware of changes in programming language and hardware platforms and the innovations in terms of tools coming out of open-source communities.[151]

It was suggested that safety specialists tend to be 'paper-based' and traditional, and perhaps not as tech savvy as might be desirable. Stakeholders underlined the need for more holistic and skills-based formal safety and risk management, including the knowledge of regulation, as just one part of a broad-based and agile understanding of safety requirements and implications. Safety and risk courses could support engineers in many different sectors; it was observed by industry professionals that "safety and risk are very horizontal" and with certain procedures needed across very different industrial settings.

There is a need for skills for safety compliance and awareness that can be specific to emerging technologies, which will require teams to be able to carry out formal risk assessments. For robotics, specifically, one safety compliance requirement might be around awareness lockout/tagout (LOTO). While this is intended to avoid injuries in the event of unexpected startup, this requires power to be turned off, which is not always possible. In this sense, to ensure safety workplaces need to rely on the training, skills and judgement of workers.

Another safety skill highlighted by our horizon scanning exercise and interviewees across sectors is awareness of the 'human factor' in human-machine cooperation. Workers need to be trained to know how and when to intervene safely in a disruption from an autonomous system. They should be able to assess whether a machine is stopping following regular procedure or due to a fault.[152] Workshop participants highlighted how difficult it can be to ascertain whether an autonomous system is functioning as intended, and suggested that 'design for safety' – wherein safety features are fully incorporated at the early design-stage rather than as a bolt-on – is a key way of decreasing risks that happen with human-machine interaction incidents.

Emerging technologies are also increasing the need for the ability to provide changing, and more stringent, certifications. Roles like a functional safety engineer in robotics will need skills to understand and analyse the certification requirements for robotic based systems. They will need to be able to develop and document the safety concept, for example, for collaborative robot systems, provide advanced robotic software functions, and collaborate with product development teams to integrate functional safety early in the design process.[153] Industry professionals highlighted that when "procuring a piece of IT there are standards on how [they] are mitigating security risks, [but] I'm not sure it happens for other types [of technology]". It was suggested that there needs to be greater attention to the right questions: for example, when deploying a [IoT] sensor, the engineer might have carried out a cyber security certification, but might have not accounted for mitigating the possibility of jamming WiFi signals.

Increased cyber security skills will also be required due to the safety implications outlined above, both in terms of IoT and RAS. Some commercially available robots are starting to be equipped for cyber safety, including with Beam Pro encryption.

The increased use of public key infrastructure (PKI) security and digital certificates requires skills that are in short supply, according to research from Ponemon Institute.[154] Ethical hacking skills are also in higher demand as they can allow companies to identify the vulnerabilities in their IoT systems.[155] Because of the increased importance of networks due to the data collected by IoT and the controls needed for RAS, wireless network security skills are becoming more important.[156]

Technical skills

- **We find evidence that more holistic or interdisciplinary approaches and knowledge will be required – especially among those leading teams of wider engineering specialists. Furthermore, cross-cutting knowledge of programming languages will likely become more important as these come to underpin more and more of the engineering landscape.**
- **Increasingly widespread digitisation will similarly generate a vast amount of data, requiring specialist knowledge and tools relating to data analysis and data management.**

148 Ibid.
149 Hussain, F, Hussain, R, Hassan, SA, and Hossain E (2019) Op cit.
150 Hetler, A and Lutkevich, B (2023) Top 7 must-have IoT skills to boost your career. [online] Available at: www.techtarget.com/whatis/feature/Top-7-must-have-IoT-skills-to-boost-your-career [Accessed 2023].
151 Osborne, B (2018) The IOT security skills gap. [online] Available at: www.resources.infosecinstitute.com/topic/the-iot-security-skills-gap/ [Accessed 2023].
152 Robots.com (nd) Education, training, and awareness are mandatory for industrial robot safety. [online] Available at: www.robots.com/articles/education-training-and-awareness-are-mandatory-for-industrial-robot-safety [Accessed 2023].
153 Agile Robots AG (nd) Functional safety engineer. [online] Available at: www.agile-robots.com/functional-safety-engineer/ [Accessed 2023].
154 Ponemon Institute (2021) 2021 Global PKI and IOT trends study. [online] Available at: www.entrust.com/lp/en/global-pki-iot-trends-study [Accessed 2023].
155 Osborne, B (2018) Op cit.
156 HM Government (2014) Cyber security skills: a guide for business. [PDF] HM Government. Available at: www.assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/386248/bis-14-1276-cyber-security-skills-a-guide-for-business.pdf

- **Specialist technical knowledge relating to specific forms of technology will also be needed; in the case of new energy sources, this may include in-depth knowledge of manufacturing processes.**
- **Specific design skills will also be required, such as computation geometry and circuit design.**

The technical skills needed within engineering will also change as a result of emerging technologies. Across the horizon scan and interviews, there are signals there will be an increased need for engineers with more holistic or interdisciplinary understandings. This is specifically in terms of people who might be leading teams of engineers with different types of specialities.

Participants suggested that engineers will increasingly need to have skills outside of their traditional understanding of the quantitative mathematical background: "I think there is going to be a need for people to understand programming better so they can understand AI". For instance, an engineer that works with new types of fuels and energy sources, might need a better understanding of chemistry and physics.[157] For hydrogen-related roles, there will be an increased need for understanding of technology areas "such as crude and distillation, reforming, alkylation, solvent de-asphalting, hydrogen manufacturing".[158] For RAS, skills in robotic programming need to interface with skills around how RAS interact with hardware, electronics and the real world,[159] and engineers will need skills in digital electronics and microprocessors, as well as biocybernetics.[160] A related need is that of understanding and analysing the wealth of data that will come from increasing digitisation and automation.

In terms of planning and design, RAS increase the need for robot motion planning. In sectors such as aviation it increases the need for air traffic management systems.[161] Engineers will need to be skilled in computation geometry,[162] and the increasing prevalence of IoT gives rise to higher demands for circuit design.[163]

There is cautious optimism about the ability of the system in the UK to provide for the transforming technical skills requirements, though industry professionals reported that this was an ongoing process of adjustment. Workshop participants highlighted that with changing needs in engineering "you still have to teach those technical skills, the fundamentals, the core civil, chemical, mechanical, electrical engineering principles that can bound any solution", but that with the accreditation history in the UK and the rigour of university courses, that is not so much a concern, even if the content changes.

Transferrable skills

- **Systems thinking, analysis and evaluation will become more valuable skills within engineering in order to optimally integrate new technologies into the industry and wider infrastructure/networks.**
- **A number of industry stakeholders suggested that the innovative adoption of new technologies will also require people who can spot promising business opportunities to add value, and incorporate new technologies accordingly. Alongside lateral thinking, consideration should also be given to the sustainability and safety implications of such decisions, requiring a holistic and long-term perspective.**
- **Some industry professionals noted a perceived tension between safety, innovation, and emerging technologies. They cautioned that while safety is of paramount importance, a 'zero incident' approach was unlikely and should not stymy positive progress. This, along with the growing role of AI, points to the need for a strong grounding in ethics.**
- **Finally, while emerging technologies will demand a greater command of certain complex digital and technical skills, it was noted that these should not preclude engineering professionals from developing baseline practical skills (such as assembly, welding and soldering).**

Where more resistance and issues might be experienced, is in the expansive, more transferrable skills that might be needed because of the changing roles of engineers. Industry professionals told us that systems thinking is going to be increasingly important to get changes in systems right, and the ability to understand, "if I make a change here [in the system], what is this going to do to the outcome". More specific skills in this sense, including for the development of RAS, relate to systems analysis and systems evaluation.[164] Systems thinking will need to be coupled with rational decision-making skills, for which individuals need an understanding of the whole system, as for example, hydrogen and its transportation requirements. Workshop participants heard the example of students at Newcastle University who are now required to employ decision-making matrices to appropriately analyse and weigh all of the relevant factors that might influence their decisions in an environment.

Related, is a need to understand the interconnectedness of the social, economic, technical and environmental context in which changes are brought about. This means that there will likely be greater needs for people who understand 'the business case' for adopting emerging technologies and who can spot opportunities to add value in operations.

However, this does not necessarily mean just understanding the economic value of employing an emerging technology in a particular field or use case, but rather it requires understanding the economic, sustainability and safety implications. Workshop participants highlighted that often "as engineers, [we] think of 'how we make use of tech at face-value rather than wider systems'. This includes being able to answer questions such as 'where does the technology come from? Where is the data generated? Who is controlling this? How will this affect wider public safety?'". Here is a reminder of the importance of systems thinking, which workshop participants identified as a valuable skill across all sectors. Participants also expanded on the significance of systems thinking skills at all levels, stating that AI engineers need to understand "how did the AI models impact their systems or subsystems", and the need for a "critical system thinker to see the loops between subsystems". In this sense, there will also be a further need for complexity science skills, stemming from the complexity that is generated when many different systems interact with each other.

There is also a need not only to understand the systems, but to encourage developments of new models. It was suggested in the sectoral workshops that this required "new thinking, freer thinking" to think outside the box, and beyond current standards, and to place this thinking within the "physical life that we are living". Workshop participants also underlined that that engineers "aren't thinking outside the box often enough".

Relatedly, there is a real tension identified between a focus on safety and innovation and emerging developments. Considering this tension, participants noted that while safety is essential, "it is not a good approach to overdo it". While it is admirable that some

157 Owen-Hill, A (2016) What is the best programming language for robotics? [online] Robotiq. Available at: www.blog.robotiq.com/what-is-the-best-programming-language-for-robotics
158 Energyskills (nd) Interim research report: hydrogen industry. [PDF] Op cit.
159 TechGig (2021) A brief guide to building a career in Robotics, Available at: content.techgig.com/technology-guide/a-brief-guide-to-building-a-career-in-robotics/articleshow/85180011.cms [Accessed 2023].
160 TechGig (2021) Ibid.
161 Alisha, S (2023) How Artificial Intelligence Is Used in Air Traffic Control (ATC) Available at: towardsai.net/p/l/how-artificial-intelligence-is-used-in-air-traffic-control-atc [Accessed 2023].
162 Schwartz, JT and Yap, CK eds (2016) Algorithmic and Geometric Aspects of Robotics (Routledge Revivals). Routledge.
163 Rajaraman, J (2020) Internet of Things (IoT) Circuit Design considerations for developers and manufacturers Available at: ts2.space/en/ai-in-robotic-air-traffic-control/ [Accessed 2023].

164 Owen-Hill, A (2016) Op cit.

companies aim for zero incidents, there needs to be a balance between zero incidents and the practical use of technology. In this sense, while the tech sector "always pushes for early adoption", "safety people can kill anything".

Further, safety is intimately tied to ethical considerations that engineers increasingly need to be able to understand and embed in their work. Participants noted that, for example, AI engineers need to not only know the algorithms, but also the ethical application of those algorithms.

While emerging technologies are highlighting the increased need of advanced new skills, there is still a debilitating lack of practical skills in workers from all educational levels.[165] For example, while programming skills for specialised software packages might be becoming more important, they must be combined with skills that include assembly, welding and soldering.[166] These constitute fundamental engineering skills that workshop participants stressed have at times taken a back seat amid the eagerness to embrace and incorporate new technologies, despite their ongoing importance. The introduction of hydrogen as a fuel source, for instance, will increase the need for suitably skilled hydrogen pipeline installers.[167]

165 Owen-Hill, A (2016) Ibid.
166 Shmatko, N and Volkova, G (2020) Bridging the skill gap in robotics: Global and national environment. [PDF] SAGE. Available at: www.journals.sagepub.com/doi/10.1177/2158244020958736
167 energyskills (nd) Interim research report: hydrogen industry. [PDF] Op cit.

RECOMMEN- DATIONS

Recommendations

Having identified the skills needed to meet the challenges of the changing engineering landscape, the question now is how those needs can be met through the skills and education ecosystem. This chapter lays out a multi-level plan to establish a pipeline of futureproof safety competencies through school, higher education, and continuous professional development. This is based not only the preceding analysis, but also a review of international best practice, workshops with industry experts, and qualitative research with relevant stakeholders.

Our recommendations consider the contribution required of different parts of the learning ecosystem, from **foundational** skills and mindsets developed in school to higher order professional skills during more specialised training in further, higher or **professional** education. Finally, it explores the **organisational** culture, support and opportunities most conducive to the engineering skills of the future. These include action that local and national government ought to take to facilitate action by employers and the sector as a whole. This is complemented in turn with brief case study vignettes of emerging and innovative practice.

All of these recommendations should be read alongside the specific skills needs identified in Chapter 3, ensuring that these efforts are tailored to the development of the most futureproof capabilities.

Foundational skills and mindsets – for policymakers, schools and colleges

- *Safety first in school-based learning.* Given the growing, and changing, role of safety in engineering roles, investment in these skills needs to start early. Experts from within the sector told us safety was all too often considered a 'bolt on' - or isolated to specific roles - when it needs to suffuse all aspects of engineering work. **Safety-related components of the digital, technical and transferable skills learnt in school should be embedded in school curricula**, for example embedding security considerations in digital learning.
- *Meeting the growth in digital skills needs.* Our analysis suggests that digital skills – especially in computer programming – are only going to become more important for engineering roles in future. The 2014 mandating of computer science education from ages 5-16 in the UK has brought welcome focus and resources to building these skills, but the subject still suffers from inequality of access and teacher shortages.[168] **Greater efforts are required to build the pipeline of computing teachers, as well as drawing on capacity and expertise within the technology sector to ensure up to date pedagogy and content.**
- *Embedding interdisciplinary approaches to learning.* This work has highlighted the growing importance of engineers being able to be literate in multiple disciplines and to manage teams with different but complementary specialisms. **Exposure to not only a broader range of disciplines for longer, as well as to the practice of combining multiple disciplines, should start in school.** In this, the UK government could take inspiration from Wales' new interdisciplinary Curriculum for Wales[169] or from the recent Times Education Commission's recommendation of a British baccalaureate, combining a broader range of six (rather than three) subjects to 18.
- *Invest in transferable skills.* There are some skills, such as interpersonal and creative problem solving skills, that all prospective engineering employees will need, especially in the future, more volatile labour market. Our analysis indicates that some of these – especially systems thinking, analysis and evaluation, entrepreneurial skills, sustainability and safety skills - can be deployed across a number of sectors and roles. **The actions described above would also offer the opportunity to instil the transferable skills identified as critical across the sector.** For example, the British baccalaureate is envisioned as including units on critical thinking, communication and creativity, as well as an extended project and community service. Development of these skills can also be supported through collaborative and problem-based learning, which is a feature of many of the case studies provided in this chapter.

168 Fowler, B and Vegas, E (2021) How England implemented its computer science education program [PDF]. Available at: www.brookings.edu/wp-content/uploads/2021/01/How-England-implemented-its-computer-science-education-program-FINAL.pdf [Accessed 16 June 2023].

169 For more information, see: hwb.gov.wales/curriculum-for-wales/introduction/

Further, higher and professional training – for further and higher education providers, local and national policymakers

- *Embrace agile and lifelong forms of learning.* As our analysis has shown, technological change and the need to decarbonise economies has increased – and will continue to increase – the rate at which skills will need to evolve. A faster evolving engineering labour market brings renewed focus to the value of transferable skills, enabling workers to upskill, change industries and occupations as needed. It also highlights the need for more flexible ways of recognising agile forms of learning, including for when formal qualifications have not yet caught up with immediate industry needs. This could take the following forms:
  1. **Initiatives like skills passports and digital badging to reward and recognise continuous learning, including in skills not yet accredited in formal learning** (see the Cities of Learning case study of digital badging working in practice, p54).
  2. **More agile forms of skills provision, such as bootcamps**, to enable rapid skilling, particularly for those already in the workforce and in need of re-training in at-risk industries and roles (see CAPSLOCK case study for an example of bootcamp-style skills provision, p54).
  3. **Local skills improvement plans**, an initiative announced in the government's Skills for Jobs White Paper,[170] bringing together employers, educational institutions and other local stakeholders to identify and meet skills needs in ways that respond in an agile and place-based way to the evolving labour market. LSIPs will be overseen by employer representative bodies (ERBs), usually local Chambers of Commerce. Members of the engineering sector should seek to engage with their local ERB to ensure skills needs in the sector are represented and responded to.
- *Ensure improved access to upskilling opportunities, especially among underrepresented groups.* Our analysis has shown that some engineering roles are more vulnerable to automation than others, in particular those of a manual or operational nature. These are simultaneously roles that are often lower paid and occupied by those with fewer qualifications. Previous RSA research has shown that workers in these positions are less likely to access training.[171] There is also an underrepresentation of women in engineering professions, as well as a lower conversion of ethnic minority groups

170 For more information see: www.gov.uk/government/publications/identifying-and-meeting-local-skills-needs-to-support-growth/local-skills-improvement-plans-lsips-and-strategic-development-funding-sdf

171 Hall, M, Mrvcic, V (2022) Scaling digital lifelong learning innovations in the UK. [PDF] RSA. Available at: www.thersa.org/globalassets/_foundation/new-site-blocks-and-images/reports/2022/09/scaling-digital-innovations-in-lifelong-learning-in-the-uk.pdf

studying STEM subjects into successful STEM careers. **Both from the perspective of inclusion and the need to ensure sufficient supply of skills in growth areas, it is important to diversify access to upskilling in engineering skills.**

- There are two aspects to this:
    1. Outreach and design of learning to suit underrepresented groups, for example through co-design with target groups and consideration of the cost and convenience of learning modes (eg travel, childcare, funding) (see CodeYourFuture and Women4Cyber case studies).
    2. Ensuring that engineering workplaces are inclusive and well suited to those groups, for example through policies around flexible or remote working.

CASE STUDY: Cities of Learning

Cities of Learning connects learning eco-systems in cities and regions to build learning pathways towards better outcomes for people, place and planet.

Currently, cities around the world are missing opportunities because vital skills learned outside formal settings go unrecognised, fragmented learning strategies add up to less than the sum of their parts, and existing learning infrastructure is too slow to respond to the rapid changes of climate, technology and industry.

Cities of Learning is a place-based intervention that brings together:

- **Digital infrastructure:** a scalable, responsive model of skills validation using digital badges to recognise non-accredited learning and connect pathways towards positive outcomes for people, place and planet.
- **Learning systems design:** connecting learning stakeholders and institutions with a shared vision for learning and shared language of skills.
- **Networked impact:** connecting places to share best practice and innovation in place-based learning.

The RSA Cities of Learning model has been piloted in Plymouth, Brighton, Bradford, Belfast, Tees Valley, Cambridgeshire and Peterborough, and Southampton.

CASE STUDY: CAPSLOCK

CAPSLOCK is a cyber security bootcamp delivered online. The bootcamps were developed to reskill individuals wanting to change careers and to improve diversity across genders, ethnicity, neurodiversity, and backgrounds.[172.]

The course, designed by employers, simulates a cyber security workplace to develop the applicable skills for which employers are hiring. Users join the course as a trainee cyber security consultant and are a part of a small team to solve real workplace problems. The core concepts learned include technology fundamentals, culture, risk, impact skills, and process.[173.]

Users have the option to take the course full-time or part-time and are only required to pay for the course once hired. Upon completion, CAPSLOCK graduates can receive up to five industry certifications including a Certificate of Cloud Security Knowledge (CCSK) from Cloud Security Alliance, CompTIA Security+ from CompTIA, and CAPSLOCK's own Certified Cyber Security Practitioner.

172 CAPSLOCK (nd) The course. [online] Available at: www.capslock.ac/the-course [Accessed 2023].
173 CAPSLOCK (nd) The course. Ibid.

Organisational culture, support and opportunities – for employers and the sector

- *Make safety everyone's responsibility.* Safety skills are all too often framed as an individual responsibility, for example through formal, individual certifications from engineering bodies/employers. The learning ecosystem is also somewhat fragmented, with different aspects of safety training outsourced to smaller companies. This is not in keeping with the nature of safety in complex organisations, which is the result of intersecting actions and wider culture. To offset this, **responsibility for safety skills development should rest at an organisational level, recognising the role of culture in determining safety behaviours and incentivising in-house development of skills.**
- *Improve incentives for safety training,* for example by **making it more accessible and desirable to individuals and organisations.** There are a number of innovations to draw on to make this a reality, including by making it more interactive and collaborative, as well as safer (see IChemE Safety Centre and Gleechi's VirtualGrasp). **Incentives also need to be strengthened through the role of regulators and CPD requirements to maintain registration.** These could be valuable tools in influencing the uptake of particularly relevant or urgently needed skills, for example those that support the safe adoption of emerging technologies set out in Chapter 3.
- *Build learning and organisational cultures which are open to challenge and agile to change.* In a world of ongoing technological change, organisational cultures which can quickly adapt to and incorporate innovations are essential. Developing a safety culture is critical for the same reason. Experts we spoke to highlighted how safety accidents may happen in an organisation where everyone has the right technical skills and theoretical safety skills, but where unsafe practices go unchallenged due to workers not feeling able to challenge colleagues or more senior workers. **Organisations therefore have a duty to foster a culture where challenging unsafe practices is not only tolerated but proactively encouraged.**

To make this a reality, organisations could look to the field of medicine where much progress has recently been made to incidents where there had been collective knowledge of safety issues, but which were not challenged for a variety of reasons.[174.] Some key initiatives that have been implemented include:

- Reducing hierarchical structures ('flat hierarchy').
- Introducing no-blame culture to encourage reporting and transparency.
- External reporting bodies, which offers protection for whistleblowers and ensures external transparency.
- Root cause analysis training, which moves focus from outcomes to causes.

174 Clinical Human Factors Group (CHFG) (nd) Introducing CHFG Human Factors Training. [online] Available at: www.chfg.org/ [Accessed 2023].

CASE STUDY: IChemE Safety Centre

IChemE case studies are a training resource focused on process safety that draws on real-life scenarios across a wide range of engineering fields. Each presents an accident in a real-time setting and the various complex causes leading up to it. The approach is interactive and facilitated, requiring participants to make safety decisions at key moments. Crucially, the ultimate outcome of the accident is not known in advance, so participants are able to observe how their decisions play out in the scenario without the benefit of hindsight.[175.]

The trainings are designed with a variety of audiences in mind – ranging from operatives to executives. In line with our recommendation, this can support a whole organisation orientation towards safety management.

Although these trainings were specifically designed to be used in workplace settings, one research team explored whether it could be delivered in academic settings. They found that with adaptations they could also be used in range of safety-oriented and technical courses at University College London.[176.] A team at Imperial College London has also detailed how they use IChemE case studies as part of their safety teaching in chemical engineering.[177.]

CASE STUDY: VirtualGrasp – Gleechi

Virtual reality is being used to support the development of technical skills in a safer and less expensive way. Gleechi's VirtualGrasp is a software development kit that allows users to train in complex environments safely and as natural to real-life as possible through virtual reality. VirtualGrasp differentiates itself from other VR with its natural grasp configuration and easy interactive behaviour setup that allows for seamless integration to the user's physical environment and its objects.[178.]

With VirtualGrasp, Gleechi notes that organisations can reduce travel and training costs while users can learn by working in a safe environment reflecting real-life operational scenarios. The technology can be particularly useful for simulating dangerous environments or scenarios and enabling practice in a risk-free space. Participants are able to make mistakes without real-world ramifications and repeat scenarios until they achieve mastery of a skill. VirtualGrasp is used in various sectors including healthcare and manufacturing.[179.]

Recently, Gleechi announced a collaboration feature that would support multiple users remotely interacting in a shared VR environment. This development would allow teachers to interact with trainees in real-time training scenarios.[180.]

175 IChemE (nd) Case studies. [online] Available at: www.icheme.org/knowledge/safety-centre/case-studies [Accessed 2023].
176 Kerin, TC, Pollock, M (2019) Application of case study material in undergraduate learning. [PDF] Chemical Engineering Transactions. Available at: www.discovery.ucl.ac.uk/id/eprint/10116880/7/Pollock_065.pdf
177 Tighe, CJ, et al (2021) Sharing good practice in process safety teaching. [online] Available at: www.sciencedirect.com/science/article/abs/pii/S1749772821000257 [Accessed 2023].
178 Gleechi (nd) Welcome to VirtualGrasp documentation. [online] Available at: www.docs.virtualgrasp.com/index.1.2.0.html [Accessed 2023].
179 Gleechi (nd) Transform your workforce with scalable, hands-on VR training. [online] Available at: www.gleechi.com/blog/evolving-vr-training-with-collaboration [Accessed 2023].
180 Gleechi (nd) Evolving VR training with collaboration. [online] Available at: www.gleechi.com/blog/evolving-vr-training-with-collaboration [Accessed 2023].

CASE STUDY: Women4Cyber

Women4Cyber is a cyber security organisation with a mission to promote, encourage, and support women in cyber security. As a part of this mission, Women4Cyber identifies and cultivates communities to develop networking opportunities and promote the voices of women in cyber security. With 19 national chapters across Europe, the organisation also aims to impact EU policy and actions to further support their community.[181.]

Women4Cyber also offers a mentorship programme tailored for upskill, reskill, and entry into cyber security while providing mentees with visible role models.[182.]

The Women4Cyber Academy delivers targeted training from a broad range of European cyber security providers. Providers can gain visibility while learners are offered opportunities for discounts and various benefits.[183.]

CASE STUDY: CodeYourFuture

CodeYourFuture (CYF) trains individuals from disadvantaged backgrounds in web development. Those eligible for the free, flexible course include refugees or asylum seekers and those with mental health, learning or physical difficulties.[184.] CYF is operated in five regions - West Midlands, Scotland, London, the north-west of England, and Cape Town.[185.]

Training on skills including coding and professional development is delivered by volunteers from the tech industry. Courses are comprised of software and professional development skills providing students with confidence and self-esteem upon graduation, with 70 percent of CYF graduates having entered the tech industry, joining both established organisations such as Capgemini, Deloitte, and startups such as Adzuna.[186.]

181 Women4Cyber (nd) Our Chapters. [online] Available at: www.women4cyber.eu/chapters/ [Accessed 2023].
182 Women4Cyber (nd) Women4Cyber mentorship programmes. [online] Available at: www.women4cyber.eu/mentorship-programmes/ [Accessed 2023].
183 Women4Cyber (nd) Women4Cyber academy. [online] Available at: www.women4cyber.eu/w4c-academy/ [Accessed 2023].
184 CodeYourFuture (nd) Become a student. [online] Available at: www.codeyourfuture.io/become-a-student/ [Accessed 2023].
185 CodeYourFuture (nd) Regions. [online] Available at: www.codeyourfuture.io/regions/ [Accessed 2023].
186 CodeYourFuture (nd) About CodeYourFuture. [online] Available at: www.codeyourfuture.io/about/ [Accessed 2023].

CONCLUSION

5

Conclusion

This report has identified a number of key skills that will be central to the safe adoption of emerging technologies. However, it is not simply the case that specific technical/specialist skills are becoming more or less important, but also that broader skills groupings are subject to change: transferrable and cross-disciplinary skills, for instance, will take on increasing importance and provide security as the world of engineering becomes increasingly changeable.

Correspondingly, it will not be sufficient to merely add new skills into existing practices. Amid considerable demographic, technological and sectoral changes, employers, educators and governments will all have to refresh established processes and ways of doing things in order to fill gaps and mitigate against disruption. These forces should draw attention to not only the 'what', but also the 'how' question of skills provision.

The world of engineering can anticipate considerable transformation over the coming years as a result of demographic trends, technological changes, and the imperative of decarbonisation. These forces will jointly see industry-wide and sector-specific changes that will impact differentially on distinct geographies, workers and sub-sectors of the industry.

Automation is expected to bring about net job creation, but steps should be taken to mitigate disruption among workers with fewer transferrable skills, particularly process, plant and machine operatives. Meanwhile, decarbonisation will impact disproportionately on certain heavy industries and their associated geographical communities. Early intervention to re/upskill affected workers might focus on building their transferrable skills to ensure horizontal adaptability across the sector, and building out specialist technical skills relating to new technologies. Technologies will impact directly on skills, but skills provision can also insure against technological disruption to the sector and its workforce.

This would reflect part of a broader movement that we deem necessary towards the in-housing of continuing professional development as large organisations will have less recourse to filling skills gaps through (ever more competitive) recruitment of a dwindling and increasingly global workforce. Governments would similarly do well to invest in training more engineers domestically, including by widening access to the sector, diversifying the engineering workforce, and improving incentives and guidance for prospective students of engineering.

Emerging technologies will bring with them considerable opportunities for improving worker safety – including automating and/or de-risking hazardous tasks – and environmental protection – for instance, through more efficient and/or low carbon production and distribution. However, they present technical and logistical challenges and hazards, and they risk opening up vulnerabilities with regards to privacy and cyber security.

The safe and effective adoption of these technologies will therefore require new skills that are currently largely lacking from the sector and from much of the engineering pipeline. Educators would do well to incorporate the skills herein identified into their curricula (including not just technical competencies, but also ever more important meta-skills), and employers should anticipate investing more into in-work continuing professional development to keep pace with the evolving skills landscape.

APPENDICES

6

Appendices

Appendix 1: Literature review methodology

The sources considered in our literature review were derived from a combination of targeted selection (eg O*NET, Royal Academy of Engineering) and Google search. Our Google search was conducted between May and October 2022 and limited to the first 40 hits. No explicit restrictions were placed on geographical regions, though only English language sources were consulted; the majority of relevant skills frameworks were sourced from Europe, North America and Oceania. Attention was restricted to the past 10 years unless by exception (eg, a seminal report), and researcher discretion was used to filter sources for quality, robustness and relevance.

Given our focus on industry-led research also conducted targeted searches of the websites of key organisations likely to produce information relevant to our topic: namely, EngineeringUK, the Engineering Council, the Royal Academy of Engineering, the Institution of Engineering and Technology (IET), World Economic Forum, High Value Manufacturing Catapult, SkillsFuture Singapore, and International Maritime Organization.

Engineering skills literature review search terms

The literature review focused on engineering broadly, as well as considering the two largest engineering sectors in the UK: manufacturing and construction. We also considered maritime/marine engineering to inform our case study for the sector.

Example search terms

- <Insert sector> AND engineering* AND skills AND framework
- <Insert sector> AND engineering* AND skills AND emerging technologies
- <Insert sector> AND engineering* AND digital AND skills
- <Insert sector> AND engineering* AND safety* AND skills
- <insert sector> AND future AND skills

In certain cases, we opted to iterate on specific topics to ensure good coverage of key points and themes that emerged by 'snowballing' from in-text references where we deemed these to be relevant and valuable.

The primary focus of the literature review was to find industry skills frameworks, occupational classification schemes, strategic government documents and other resources detailing specific skills demands. Our literature review was also informed by recommendations from our project partners at the University of York.

We were guided by four primary enquiry questions and following an initial review of the literature, we excluded sources that we did not deem sufficiently relevant. The four primary enquiry questions focused on:

1. **Defining engineering:** how does this research identify or define relevant engineering occupations and/or sectors?
2. **Methods:** how does this research identify skills demands – what methodologies do they deploy?
3. **Future engineering jobs and skills:** what predictions are being made in terms of job creation/skills demands and what emerging technologies are identified as important for the future of engineering. What is the role of safety skills in any adoption hypothesis?
4. **Challenges and opportunities:** what are the main challenges for adopting new technologies, and the main barriers to upskilling and reskilling. What innovations are emerging to address these challenges?

Our analysis and synthesis followed a standard literature review method; namely, we read each source, identified relevant themes and the research questions each source related to, and recorded the relevant findings. These findings were then synthesised by combining material around relevant questions and skills categories.

From the shortlisted literature, frameworks and reports were included where they provided an overview of engineering capabilities and skills, whether this was at a general level (ie targeting all engineering professions or engineering in the broadest sense) or more specific (concentrating on one type of engineering/engineering-related role).

Reports from a wide geographical area were reviewed to give a global view of engineering, although the focus ended up being primarily on Europe, North America and Oceania, as well as only English-language sources. Two reports focusing on regions with important engineering and manufacturing sectors (in this case in the UK) were included to provide some more localised perspective on skills requirements. One consistent issue with the variety of reports is the level of granularity that each goes into in terms of skills and skills. This can range from quite a high-level (eg O*NET's Engineering and Technology—Knowledge of the practical application of engineering science and technology) to the specific (eg International Council on Systems EngineeringUK's Behavioural Analysis—Event Simulation).

Appendix 2: Skills data analysis

Data analysis methodology: ESCO Skill-Occupation Matrix Tables and automation risk data

Along with the US O*NET, the ESCO is one of the most well known and widely used skills frameworks. It has been developed and maintained by the European Commission and can be accessed in a range of different formats. The ESCO Skill-Occupation Matrix Tables aim "to unravel the complexity of the ESCO dataset through more dynamic illustrations of how ESCO concepts can be connected and used at more aggregated levels".[187] Specifically, it includes scores that indicate the prevalence of different ESCO skills (and skill groups) for different occupations (and occupation groups) based on algorithms that match the descriptions of skills and occupations. We use this as a proxy for skill importance.[188]

Since the international ESCO dataset links EU ISCO-08 rather than UK SOC to skills data, we first map UK SOC to ISCO to translate across the engineering footprint definition that our analysis is based on. To do this, we use data tables that have been developed by the ONS. Weighted scores are then calculated as the ESCO skill-occupation matching score for each occupation multiplied by the total engineering employment in each occupation. This ensures that our analysis gives greater weight to skills where a larger number of workers are employed, as some SOC and ISCO codes may be relatively niche compared to others.

Furthermore, this analysis is informed by findings from our literature review. ESCO consists of eight broad categories. As a general framework it does not neatly align with industry perceptions of engineering skills meaning that the categories, which we have used, often span multiple ESCO categories. As a result, we manually tagged the dataset based on the research team's assessment of whether, in the context of engineering, they are best described as technical, transferable, digital or safety skills.

We use automation risk ratings based on automation risk quartiles for all occupations, including core, related and non-engineering occupations to highlight the resilience of different skills. We define a skill as important to an automation risk grouping if its average weighted score ranks in the top 50 for that group.

187 European Commission (2021) ESCO Skill-Occupation Matrix Tables: linking occupation and skill groups. [PDF] Available at: www.esco.ec.europa.eu/system/files/2023-04/en_ESCO%20Skill-Occupation%20Matrix%20Tables%20Technical%20Report.pdf#page6

188 ESCO provides the following advice on interpretation of the raw data, which we converted to rankings in our analysis: tables show in percent values the distribution of skills (or skills groups) among occupations or (occupation groups) eg when looking at clerical support workers, one can observe that workers in this group have a higher share of communication, collaboration and creativity skills, while they have a low share of handling and moving skills.

Appendix 3: Horizon scan

Horizon scanning is the act of looking for evidence of trends and emerging issues that might be important in shaping the future. Trends are clearly established or emerging patterns of behavior and illustrate the general direction of a change over time. Emerging issues (sometimes called weak signals) are nascent developments that suggest new possibilities for the future.

> *"A signal of change is like a seed of a possible future. It can be any development, idea or innovation that points to a future possibility different to today's norm... Not all signals do end up coming to fruition, because the future is inherently uncertain. Signals help us to think in terms of multiple possible futures, to think more widely and creatively about the future and to anticipate unintended consequences".*[189.]

Horizon scanning is a widely used strategic foresight method. This activity differs from our literature review particularly in terms of the breath and diversity of different sources that are considered. Weak signals are nascent developments meaning they are often found in sources such as press releases, newspaper and magazine articles and blogs, newsletters and social media posts from technology experts, rather than academic or industry research publications.

We focused the horizon scan on three major emerging technology clusters – robotics and automated systems; the Internet of Things; and hydrogen-based clean technologies. Each of these technologies exemplifies a different dimension of safety that this research considers. For example, RAS has widespread implications for worker safety, IoT for cyber security and hydrogen for environmental impacts. RAS and IoT build on previous LRF foresight work while hydrogen is included due to its centrality to the net zero agenda where it will have widespread implications across engineering sectors.

Our analysis collated indicative data points, weak signals and expert opinion in order to answer the following research questions:

- Why are engineering businesses adopting the technology? What data points are there on the pace and breadth of adoption?
- What are the main safety opportunities associated with the technology? What are unique/common safety challenges?
- What adjacent technologies are being adopted alongside this technology, particularly those that help improve safety (eg machine learning or blockchain solutions for IoT security)?
- What jobs are needed for the adoption of this technology? What impacts could it have on the structure of the workforce?
- What skills are needed for the safe adoption of emerging technologies? How do these map onto existing occupational or ESCO skill categories?

189 Forum for the Future (n.d.) The Futures Centre. Available at: https://www.gong.co/the-futures-centre.html [Accessed 2023]

Technology horizon scan search terms

Our horizon scanning approach started with broader searches and then 'rabbit holed', picking up on smaller relevant details which were tailored following searches from those. We employed this type of search strategy on Google searches, Google News, Twitter and LinkedIn. A summary of initial search terms is included in the box below.

We focused our social media searches on two platforms: LinkedIn and Twitter, which allow for Boolean search operators.

Initial search terms included:

- <insert technology> AND skills
- <insert technology> AND jobs
- <insert technology> AND safety

The same search terms were used on both Google search and Google News, as these are equipped to optimise for relevance, and Google News search to optimise for weak signals.

Initial search terms included:

- <insert technology> AND engineering* AND skills
- <insert technology> AND engineering* AND adoption OR use case
- <insert technology> AND engineering* AND skills AND jobs
- <insert technology> AND engineering* AND safety
- <insert technology> AND engineering* AND environment OR climate OR sustainability*
- <insert technology> AND engineering* AND cyber

The following search provided a combination of the above with specific industries, such as construction, manufacturing and maritime.

- <insert sector> AND <insert technology> AND engineering* AND skills
- <insert sector> AND <insert technology> AND engineering* AND adoption OR use case
- <insert sector> AND <insert technology> AND engineering* AND skills AND jobs
- <insert sector> AND <insert technology> AND engineering* AND safety
- <insert sector> AND <insert technology> AND engineering* AND environment OR climate OR sustainability*
- <insert sector> AND <insert technology> AND engineering* AND cyber

Appendix 4: Workshops and focus groups

Workshop and focus group participants were identified in consultation with Lloyd's

Register Foundation. Relevant sectors of interest (including academia, as well as sub-sectors from different parts of the engineering world) were identified, and suitable contacts identified through existing networks and internet-based searches. Participants were invited to join a two-hour interactive workshop exploring key future trends, co-designing job roles and skills that the engineering sector will need in 2040, 2060 and beyond. Questions and themes explored during the workshop included:

- What skills will be required for safely adopting emerging technologies in engineering?
- How can we ensure that these skills are provided to those who need them?

Participants were divided by sector, and discussed scenarios, skills and good practice in their particular line of work.

Figure 3: Sectoral composition of workshop attendees

Sector	Number of attendees
Consultant	12
Networks	2
Education	1
Engineer	5
Infrastructure	1
Investment	2
NGO	4
Research	2
Miscellaneous	3

Participants were invited to join via Zoom, and the workshops used the interactive Miro platform to capture notes and insights. Breakout group were self-assigned by sector/industry, and participants were invited to identify emerging skills-needs, skills-gaps, and good practice in bridging these.

A subset of workshop participants were then invited to a follow-up focus group to stress-test the findings of the research project and to co-create recommendations for the sector.

Appendix 5: Skills for assuring the safe adoption of emerging technology

The following is a deep dive, conducted by researchers from the University of York as part of this enquiry. It reflects on the existing literature relating to the safety activities that developers of systems should pay attention to, considering the implications of new technologies in their domains and the potential associated training and education needs that emerge.

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Abstract

As new and emerging technologies continue to pervade all aspects of society and commerce, we need to be confident that its adoption can and will be safe, and can be shown to be safe. A plethora of academic and grey literature considers the pitfalls and challenges to be faced by the advent of emerging technology, but offer no pragmatic steps to prepare for the safe adoption of emerging technology. The paucity of preparedness for safe adoption is underlined by the offerings of academic prospectuses - or rather the lack of offerings with regards to education and continuing professional development. Whilst we are able to highlight the challenges faced by an organisation seeking to adopt emerging technology, a substantial amount of further research is required before we can confidently recommend what competence looks like and how to provide the educational training needs associated with the safety assurance aspects of technology adoption.

Keywords: safe adoption, emerging technology, competence.

1 Introduction

New and emerging technology continues to proliferate and pervade all aspects of society. Organisations are not immune from this proliferation. Whilst the adoption of emerging technology has the potential to realise resource, time, and cost benefits for an organisation, we must also ensure the adoption is safe - for all stakeholders. The achievement of safe adoption must also be demonstrated. Key to the achievement of safe adoption is the establishment and management of competence. Competence is required of staff within an organisation, and this must be achieved demonstrably. To ensure competence, training needs analysis is required, followed by the provision of appropriate education and training at varying levels. For context, we first establish a definition for emerging technology.

1.1 What defines a technology as being 'emerging'?

Frustrated at the lack of consensus on what constitutes an emerging technology (noting that this lack of consensus impacts the development of effective regulations - which in turn impacts the available support of the technology actually emerging), Rotolo, Hicks and Martin embarked on a scientometric study to define and operationalise emerging technology.[190.] Their definition of emerging technology is as follows, and provides the context for this paper:

> *"A radically novel and relatively fast-growing technology characterised by a certain degree of coherence persisting over time and with the potential to exert a considerable impact on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes. Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous".*[191.]

Safety is a key emergent property which must be considered when adopting any technology, but it has significant uncertainty associated with it. Key decisions about the acceptability of safety lie with staff within an organisation. Further, mitigation of potential safety events is placed on operational staff using the technology. Emerging technology thus has a potentially large impact on the skills and associated competencies expected of staff in an organisation.

The rest of this paper is structured as follows. Section 2 considers what is needed to assure the safe adoption of emerging technology, section 3 assesses the state of literature on what is needed to assure the safe adoption of emerging technology, and section 4 considers what is required for effective skills management. The paper concludes in section 5 by considering future research directions that are required to confidently assure the safe adoption of emerging technology.

2 Assuring the safe adoption of emerging technology

As new, emerging technology continues to proliferate and pervade all aspects of society, organisations are increasingly adopting such technology, but is this adoption safe?

Organisations may consider adopting emerging technology for many potential reasons, but when discussing technology with respect to its safe adoption, we consider two distinct types:

- Technology adopted to improve safety.
- Technology adopted to improve factors other than safety, but which may have an impact on safety, nonetheless.

In considering the safe assurance of emerging technology we evaluate the challenges, the current state of literature regarding the safe adoption of emerging technology, academic and vocational training offerings, the impact on required staff competencies and skills, and make recommendations for future research into policy and practice.

2.1 A paradigm shift in safety assurance for emerging technology

We are currently experiencing a steady state experience-based approach to safety assurance. The last major disrupter in safety-critical systems safety assurance was the advent of control and information software in the 1990s. The advent of software required a rethink of recognised good practice which culminated in a plethora of open standards which (despite their detractors) have held firm as de facto functional safety standards (such as IEC 61508[192.] and ARP 4754A.[193.] Since the advent of software, safety assurance has been predicated on the measurement and assessment of compliance/

190 Rotolo, D, Hicks, D, Martin, BR (2015) What is an emerging technology? [PDF] Research policy.
191 Rotolo, D, Hicks, D, Martin, BR (2015) Ibid.
192 IEC (2010) Functional safety of electrical/electronic/programmable electronic safety-related systems. [PDF] IEC. Available at. www.standards.iteh.ai/catalog/standards/iec/c31782f4-a45f-49d7-ace1-462e037ab2c6/iec-61508-1-2010
193 SAE Aerospace (2010) Guidelines for Development of Civil Aircraft and Systems ARP4754A. [online] Available at: www.sae.org/standards/content/arp4754a/

conformance with these standards, and there are no signs of any paradigmatic shift away from the processes and procedures currently described by the standards.

The advent of new, emerging technologies such as robotics and autonomous systems, and new ways of developing software (such as machine learning), represent a new, disruptive technology for which the existing safety standards are no longer relevant. A paradigm shift is required towards responsible innovation. Responsible innovation is defined by UK Research and Innovation (UKRI) as being:

> *"A process that takes the wider impacts of research and innovation into account. It aims to ensure that unintended negative impacts are avoided, that barriers to dissemination, adoption and diffusion of research and innovation are reduced, and that the positive societal and economic benefits of research and in-novation are fully realised".*[194.]

In a shift away from extant recognised good practice of the kind espoused by open standards, responsible innovation requires stakeholders themselves to determine and justify what 'good' looks like - and emergent technology such as RAS also implies that a new set of skills are required, including what is often referred to as soft skills.

Soft skills involve the ability to undertake activities such as critical thinking, and the ability to develop alternative solutions, and judge these alternatives. We argue that the existing frameworks for managing safety competence and competencies are not fit for purpose when considering the new skills that emerging technology will necessitate, nor is there any sign that such frameworks are being reviewed/updated by stakeholders such as professional institutions.

3 The state of literature with regards to the safe adoption of emerging technology

In this section we consider existing literature into the process of safely adopting emerging technologies, their associated competencies, and the current offerings of educational institutions with regards to equipping the current and future workforce for the safe adoption of emerging technology.

We have considered four main types of literature in our research:

- Governmental and organisational white papers.
- Academic papers.
- Grey literature (from organisations such as the Institution of Occupational Safety and Health etc).
- Prospectuses of educational training providers.

These sources are considered collectively under four main themes, which are considered in turn:

1. Organisational.
2. Technical.
3. Regulation and governance.
4. Training, skills, knowledge and competence.

194 UK Research and Innovation (UKRI) (2023) Responsible innovation. [online] Available at: www.ukri.org/about-us/policies-standards-and-data/good-research-resource-hub/responsible-innovation/ [Accessed 2023].

3.1 Organisational

Barwell et al suggest the following checklist that an organisation could employ when considering the adoption of emerging technology.[195.] We have added to their original questions to specifically consider the safe adoption of emerging technology:

1. Will the technological solution provide the benefits expected?
   - Is the technological solution aiming to provide safety improvements? How will the technological solution contribute to existing safety?
   - Is the safety contribution positive or negative?
   - Will the technology employ architectures that ensure safety?
2. Can the technological solution be integrated with the existing systems in a safe manner?
   - Can the proposed socio-technological solution be integrated effectively into the existing safety management system?
3. What new safety risks will a technological solution introduce into an organisation?
   - How will any new risks be managed?
4. What impact will the technological solution have on the working practices of those engaged in developing safety systems and safety assurance activities?
   - What impact will the technological solution have on competence and competencies?

3.2 Technical

As more technologies are developed/adapted for safety purposes, it is essential to unearth ways to improve the integration of technology within safety management practices.[196.] A common failing when adopting emerging technologies is systems integration, along with an incurable belief that technology on its own will yield positive results (ie not considering requirements on staff and staff training etc).[197.] Further, organisations are not considering the relevance of ongoing risk measurement and assurance work as part of their training needs analysis.

New technologies such as RAS and ML change the interaction between humans and machines. They alter the ability of staff to maintain situational awareness. Thus, technology change will delete elements of organisational roles, as well as adding new elements and changing others. This mix of unlearning, learning, and changing of competencies and skills is a significant challenge in terms of professional development, both initial and continuing.

3.3 Regulation and governance

Naturally, regulation is only pertinent to regulated industries, but the act of regulation is analogous with governance for internal (to the organisation) assurance needs. Emerging technology may break primary legislation under which regulation/governance personnel work, and it also poses unique issues for regulation and governance - not least when considering the competency needs of regulators and governors. Back in 2010, Downer highlighted the issues the Federal Aviation Administration (FAA) had; being wholly unable to hire and retain experts who could understand the increasingly complex technologies involved.[198.]

Studying the conundrum faced by the FAA, Downer noted that "high-technology regulators contend with an intractable technical problem by turning it into a more tractable social problem, such that, despite appearances to the contrary, the FAA quietly assesses the people who build aeroplanes in lieu of assessing actual aeroplanes".[199.]Emerging technology (especially novel and/or radical technology) may not be readily accepted by users nor society at large should the regulation and governance philosophy be predicated on assessing the "creditworthiness of the people who make the technological claims" (instead of the technology itself directly).[200.]

There is a training/educational steppingstone capability required of staff who accept new technology into service, and they must have the ability to turn exemplar acceptance practice into policies and regulations for novel safety solutions.

The advent of emerging technology challenges the regulation and governance mechanisms used with the current compliance-based approaches and suggests a move towards a more goal-based approach to the development of safety architectures - generating safety evidence and argumentation within a responsible innovation framework.

The current approach has been codified into standards, but emerging technology represents a step-wise progression of existing technology, and not an incremental change of it. The implication of this is that we will require all stakeholders (but specifically regulators) to determine:

1. What responsible innovation looks like in practice.
2. What good adoption processes and competent staff comprise.
3. Who does what (developers, safety professionals, and regulators).
4. Blockers and gap analyses for who does what (currently).
5. Possible improvements to extant regulations, policies, and processes.

There are a lack of internationally recognised safety governance mechanisms for developing and using emerging technologies, for example AI technologies in health care.[201.] The use of emergent technologies such as AI (particularly in health applications) raises safety and ethical concerns that still need to be addressed by appropriate governance mechanisms.[202.]

However, a lack of skills, capabilities, and knowledge with local regulator workforces is a significant barrier to remediating current and future gaps in areas such as medical device regulation. It could be argued that cohesion across international regulatory frameworks could help redress the imbalance of regulatory experience and skills between nations.[203.]

From an employer's perspective, an inherent problem stems from the lack of certainty in regulation.[204.] In considering the challenges of adopting novel therapies, Webster and Gardner bemoan the need to overcome issues of utility, novelty, cost, and skills demand - noting also that there exists the challenge of finding the right regulatory framework.[205.]

195 Barwell, A, Stewart, D, Hoad, R (2020) Technology adoption hazards - challenges and pitfalls in adopting new technology. [PDF] Qinetiq. Available at: www.qinetiq.com/-/media/6e04de90b6a84126b5f15d028290435b.ashx
196 Nnaji, C, Gambatese, J, Karakhan, A, Eseonu, C (2019) Influential safety technology adoption predictors in construction. [PDF] Engineering, Construction and Architectural Management.
197 Barwell, A, Stewart, D, Hoad, R (2020) Op cit.

198 Downer, J (2010) Trust and technology: the social foundations of aviation regulation. [PDF] The British Journal of Sociology.
199 Downer, J (2010) Ibid.
200 Downer, J (2010) Ibid.
201 Morley, J, Murphy, L, Mishra, A, Joshi, I, Karpathakis, K, et al (2022) Governing data and artificial intelligence for health care: Developing an international under-standing. [PDF] JMIR formative research.
202 Morley, J, Murphy, L, Mishra, A, Joshi, I, Karpathakis, K, et al (2022) Ibid.
203 Morley, J, Murphy, L, Mishra, A, Joshi, I, Karpathakis, K, et al (2022) Ibid.
204 Leesakul, N, Oostveen, AM, Eimontaite, I, Wilson, ML, Hyde, R (2022) Workplace 4.0: Exploring the implications of technology adoption in digital manufacturing on a sustainable workforce. [PDF] Sustainability.
205 Webster, A, Gardner, J (2019) Aligning technology and institutional readiness: the adoption of innovation. [PDF] Technology Analysis & Strategic Management.

This is akin to the problems facing the safe adoption of RAS, for which there are no suitable standards. Calls exist to develop compliance skills for novel development assurance.

Goyal, Howlett, and Taehagh have observed that it isn't clear from the literature **how** regulation for emerging technologies emerges.[206.] Their 2021 research paper into the emergence of the EU GDPR revealed that policymaking can drive technological innovation, which then requires more policy activity.

They argue there is a fine balance between innovation on one side, and over-sight, accountability, and transparency on the other[207.], and too little / too much regulation can be counter-productive - leading to either unsafe adoption, or the prevention of acceptable innovation in emerging technologies. To deter-mine how effective any regulatory policy may be before its implementation is challenging[208.], and the increased ambiguity in the application of a regulation can contribute to a lack of harmonisation amongst stakeholders - which can lead to the framing of the lack of harmony as a policy problem.[209.] This has implications for the nature of the skills required for staff developing and implementing regulatory frameworks. Staff need reviewing, critical evaluation, and regulation adaptions skills to be effective.

3.4 Competency - knowledge, skills, and behaviours

When considering the needs of organisations to educate their staff in the necessary skills for safe adoption, one must consider all the stakeholders in any education process; employers, employees, training providers, and their expectations.[210.] Gajek et al cite three routes to process safety education:

- Education institutes such as Universities – Professional Training / OJT.
- Training in governmental regulatory agencies.

They further assert that the traditional university method is not well suited to dealing with the complex interactions on which safety depends, and further note that only a fraction of graduates have a working knowledge of process safety topics considered important by industrial and academic safety experts. This suggests a disconnect between academic offerings and the expectations of industry.[211.]

Experience from CPD and university-led teaching of safety at the University of York implies that this remains the case currently. It is only being made worse as new technologies become more complex, and have more capability to make decisions which have safety implications. Educating for variation of best safety assurance practices due to new technology is difficult when there is already a skills gap in industry. As new techniques and methods are generated to address the needs of decision-making systems interactions between academia and industry are required to pull these through to training needs analysis and industrial practice. The core techniques and methods, and associated skills, have not changed significantly in 20 years and this interaction is thus not a standard part of the interaction between industry and academia.

206 Goyal, N, Howlett, M, Taeihagh, A (2021) Why and how does the regulation of emerging technologies occur? explaining the adoption of the eu general data protection regulation using the multiple streams framework. [PDF] Regulation & Governance.
207 Goyal, N, Howlett, M, Taeihagh, A (2021) Ibid.
208 Kobos, PH, Malczynski, LA, La Tonya, NW, Borns, DJ, Klise, GT (2018) Timing is everything: A technology transition framework for regulatory and market readiness levels. [PDF] Technological Forecasting and Social Change.
209 Goyal, N, Howlett, M, Taeihagh, A (2021) Op cit.
210 Gajek, A, Fabiano, B, Laurent, A, Jensen, N (2022) Process safety education of future employee 4.0 in industry 4.0. [PDF] Journal of Loss Prevention in the Process Industries.
211 Gajek, A, Fabiano, B, Laurent, A, Jensen, N (2022) Ibid.

The contribution of professional institutions (such as the Institution of Engineering and Technology which publishes codes of practice for safety professionals), colleges and universities, and other external providers is surprisingly low, perhaps because employers consider training by universities not practical enough, and universities may not teach process safety as the lecturers have not worked in industry.[212.] There remains a credibility gap between industrial practitioners and educators.

Moving away from safety specifically, Naiseh et al assert that graduates are not equipped to apply their training to real-world situations and suggest that promoting the awareness of the interdisciplinary nature of new technology such as trustworthy autonomous systems (TAS), is the main gap in current TAS education.[213.]

Many of the TAS experts questioned by Gajek et al found it difficult to imagine core topics and skills before more research is undertaken, and asserted that there are a serious lack of relevant studies, particularly in planning, implementing and conceptualising TAS curricula.[214.]

This is borne out by experience in programmes such as the Assuring Autonomy International Programme (AAIP), where we have asked demonstrator projects to provide quarterly an indication of the required knowledge, skills, and behaviours implied by their demonstrator activities. However, most are unable to provide this, even when prompted and supported. The emerging needs for education and training does not appear to be within the current capability of development organisations. This implies that updated policies, and methods and techniques for training needs analysis (TNA) are required to support innovative organisations. There is an open question as to whether developers of regulations/frameworks should have arguments and evidence of competency and training needs as an explicit certification requirement.

Workers will need skills and competencies higher up the Bloom taxonomy scale,[215.] which implies a need for higher level qualifications as their roles are becoming increasingly more complex, with tasks shifting from routine processes to controlling machines in real-time by incorporating analytical information given by new software.[216.] Workers will also need to have digital, soft, business, and management competencies, along with mental, practical and personality skills.[217.]

Research cited in Leesakul et al suggests that skills generally have a half-life of about five years, with more technical skills at just two and a half years.[218.] This poses a question as to whether professional titles such as chartered engineer should be formally reviewed every five years. These reviews should have appropriate criteria that ensures renewal is not a tick-box exercise. The professional institutions that bestow such titles (such as the Engineering Council) should therefore revisit their code of practice for competency in areas such as safety engineering and safety assurance to address the skills half-life.

Considering safety professionals specifically, Provan et al note that "safety is a complex socio-technical discipline, and we do not have an agreed understanding of the knowledge and skill requirement for safety professionals".[219.]

When considering the required education, training, skills and knowledge, the IET and HSE provide helpful definitions for the distinction between competence and competency:

212 Gajek, A, Fabiano, B, Laurent, A, Jensen, N (2022) Op cit.
213 Naiseh, M, Bentley, C, Ramchurn, SD (2022) Trustworthy autonomous systems (tas): Engaging tas experts in curriculum design. [PDF] arXIV.
214 Naiseh, M, Bentley, C, Ramchurn, SD (2022) Ibid.
215 Bloom, B (1956). Taxonomy of Educational Objectives. Book I: Cognitive Domain. New York: David Mckay.
216 Leesakul, N, Oostveen, AM, Eimontaite, I, Wilson, ML, Hyde, R (2022) Workplace 4.0: Exploring the implications of technology adoption in digital manufacturing on a sustainable workforce. [PDF] Sustainability.
217 Gajek, A, Fabiano, B, Laurent, A, Jensen, N (2022) Op cit.
218 Leesakul, N, Oostveen, AM, Eimontaite, I, Wilson, ML, Hyde, R (2022) Workplace 4.0: Exploring the implications of technology adoption in digital manufacturing on a sustainable workforce. [PDF] Sustainability.
219 Provan, DJ, Rae, AJ, Dekker, SW (2019) An ethnography of the safety professional's dilemma: Safety work or the safety of work? [PDF] Safety Science.

Competence: the ability to undertake responsibilities and perform activities to a recognised standard on a regular basis.

Competency: a specific knowledge, understanding, skill, or personal quality that an individual may possess. The sum of an individual's competencies will make up their competence, and it is these individual competencies that are assessed in order to provide an overall indication of competence.[220.]

This concept of competency can be extended from the individual to a team of people undertaking a set of coordinated tasks that are aimed at some goal. The competency of a team is not merely the sum of the competencies of the individual team members because of the social interactions between the team. Team competency for safety work is particularly important as the work can be highly distributed with a number of members of the team not being under direct line management of safety managers. This is an underexplored area of the skills required for safe adoption of new technologies.[221.222.223.]

What constitutes individual and team competence, however, is challenged with the advent of emerging technology, and individual competency requirements must be identified, and managed pertinent to the technology, organisation, role, and individual.

A recent UKRAS report has projected to 2030 and has asserted what skills will be required by then; noting that the rapidly developing capabilities of technologies such as autonomous systems are thought to herald a new machine age that will dwarf previous waves of innovation, in terms of the scale, speed, and scope of the disruption it creates. For example, in the specific context of RAS, what the workforce of 2030 will be required to do is to problem solve alongside the machines and technologies of the 4IR,[224.] and increasingly act as strategic decision-makers.[225.] This will require human-robot co-working skills and a significant change in the soft, as well as technical, skills of individuals.

A 2017 report from Deloitte frames the educational/vocational research need quite well, asking:

"How can the training system equip workers in the future to respond to automation and digitalisation? And how can it be sure it is training for the right skills while at the same time enabling those already in work to acquire new, future-oriented skills?"[226.]

The implication of increasingly complex systems, and decision-making systems, is that the workforce will also need to have systems' understanding,[227.] and it will be important for organisations to find staff not only with the appropriate skills but also who are motivated, open to, and curious about acquiring new knowledge and new skills.[228.] The acceptance by workers that skills and competency are time limited, and a clear pathway to update skills is required. Only a limited number of professions, such as the medical profession, have such cultures and pathways in place. This culture change may be a significant barrier to safe adoption in the engineering community.

220 IET Standards (2017) Code of Practice: Competence for Safety Related Systems Practitioners. IET Standards.
221 Miller, KK, Riley, W, Davis, S, Hansen, HE (2008) In situ simulation: a method of experiential learning to promote safety and team behavior. [PDF] The Journal of perinatal & neonatal nursing.
222 Margerison, C (2001) Team competencies. [PDF] Team Performance Management: An International Journal.
223 Alidrisi, HM, Mohamed, S (2022) Developing a personal leadership competency model for safety managers: a systems thinking approach. [PDF] International journal of environmental research and public health. Available at: www.ncbi.nlm.nih.gov/pmc/articles/PMC8871654/
224 Waterstone, R, Charlton, P, Gibbs, D, Prescott, T (2021) Preparing the workforce for 2030: skills and education for robotics & autonomous systems. [PDF] UK-RAS. Available at: www.ukras.org.uk/wp-content/uploads/2021/07/UK_RAS_wp_skills_education_web_144dpi.pdf
225 Leesakul, N, Oostveen, AM, Eimontaite, I, Wilson, ML, Hyde, R (2022) Workplace 4.0: Exploring the implications of technology adoption in digital manufacturing on a sustainable workforce. [PDF] Sustainability.
226 Zobrist, L, Brandes, D (2017) What key competencies are needed in the digital age? The impact of automation on employees, companies and education. Deloitte. Available at: www2.deloitte.com/content/dam/Deloitte/ch/Documents/innovation/ch-en-innovation-automation-competencies.pdf
227 Zobrist, L, Brandes, D (2017) Ibid.
228 Zobrist, L, Brandes, D (2017) Ibid.

We find that there is a lack of academic research with regards to how the adoption of emerging technology can be safely assured. Although some recommendations are made, the majority of uncovered literature only serves to highlight perceived issues.

Further, there appears to be a degree of consensus that universities need to continuously adapt their curricula to stay relevant for the skills requirements (of these jobs). However, university curricula are relatively slow to change with significant time lags to implementation due to the way that student engagement in change is managed. Business and soft skills (including critical thinking and analytical skills) are as important as hard technical skills. In fact, the lack of critical thinking skills appears to be a significant barrier to industrial safe adoption of new technologies. Critical thinking and decision-making skills are vital for both AI and ML assurance roles.[229.]

Organisations, and training and continuing professional development providers must provide deeper and more intensive reskilling experiences and provide their employees relevant time for this learning as part of their change-management and future workforce's planning efforts.[230.]

Webster and Gardner suggest we could look to institutional readiness levels - orthogonal levels of readiness that are designed to employ "trans-organisational expertise and participation in helping to 'ready' diverse actors to undertake more workable, doable technological innovation".[231.]

However, it will be necessary to rethink traditional learning methods to attain transferable skills such as creativity, problem solving, critical and systems thinking, and emotional intelligence.[232.]

In their paper, Naiseh et al make four recommendations to counter the skills issue and promote the interdisciplinary nature of TAS:[233.]

1. Increase interdisciplinary awareness.
2. Prepare appropriate logistics.
3. Increase diversity.
4. Identify the required skills.

In summary, it is clear that the approaches to the development of both soft and hard skills required to address safety and the safe adoption of complex, emerging technologies, especially those that are safety-critical in nature, has not garnered the attention of educational institutions, development organisations, nor academia - in the same manner that the technology itself has. There is a research and policy gap in this area which needs to be addressed.

Training providers

- The next question which arises is 'are there any training and education providers providing appropriate soft and hard skills in this area?' Our research suggests there is currently a lack of provision in the educational arena. The vast majority of educational institutions, vocational institutions, and CPD providers are not currently giving the safe assurance of emerging technology any consideration.

229 Verma, A, Lamsal, K, Verma, P (2021) An investigation of skill requirements in artificial intelligence and machine learning job advertisements. [PDF] Industry and Higher Education.
230 Leesakul, N, Oostveen, AM, Eimontaite, I, Wilson, ML, Hyde, R (2022) Workplace 4.0: Exploring the implications of technology adoption in digital manufacturing on a sustainable workforce. [PDF] Sustainability.
231 Webster, A, Gardner, J (2019) Aligning technology and institutional readiness: the adoption of innovation. [PDF] Technology Analysis & Strategic Management.
232 Gajek, A, Fabiano, B, Laurent, A, Jensen, N (2022) Op cit.
233 Naiseh, M, Bentley, C, Ramchurn, SD (2022) Op cit.

- Amongst the most important challenges are the need to reskill the current workforce to work safely and effectively alongside robots, to train managers to understand and effectively deploy automation, and to ensure that, across all levels of education, people from diverse backgrounds have the requisite skills.[234.]
- Universities need to continuously adapt their curricula to stay relevant for the skill requirements of popular jobs/careers,[235.] noting that business and soft skills (including critical thinking and analytical skills) are as important as hard technical skills. Decision-making skills are critical for both AI and ML roles.[236.237.]

University course prospectuses

Of the many educational institution and universities' prospectuses we have trawled across the UK, Europe and North America, only two institutions offer any form of education concerning safety above an initial awareness level in emerging technologies such as RAS; the University of Hertfordshire, and the University of York.

- University of Hertfordshire MEng/BEng in Robotics and Artificial Technology. A review of this course's prospectus reveals the following:
    - Notes that it will generate an understanding and know-how of related disciplines, but doesn't expand on what these related disciplines are.
    - 'Safety' is listed as a constraint that the student will identify (when investigating and defining 'the problem').
    - Considers legal requirements of H&S and product safety.
    - Provides knowledge and understanding of H&S and risk assessment, and risk management techniques (but this is just one seventh of one module).
    - It is not clear if any of the above are compulsory modules.

University of York

The University of York is the only UK university to offer a MSc in Safety Critical Systems Engineering that is geared towards industrial practitioners, and is the only course that offers a formal 10 credit-bearing module on the safety assurance of robotics and autonomous systems that employ machine learning capabilities.

The safety assurance module is soon to be extended to a full 20 credits as the approach to assuring such technologies becomes more mature. To provide this education close links to the Assuring Autonomy International Programme (sponsored by Lloyds Register) was vital.[238.] As funding bodies are key enablers of research projects which contribute significantly to the growing bodies of knowledge, we argue that funders should consider making training and education a core work package in any significant grants they make to the advancement of new technologies and their industrial impact.

However, despite our educational offerings in safety-critical systems, the University of York simply cannot cater for the numbers of postgraduate students required to support the safety professional needs of the future (nor current) workforce, as capacity is limited to 20 places a year.

234 Waterstone, R, Charlton, P, Gibbs, D, Prescott, T (2021) Op cit.
235 Verma, A, Lamsal, K, Verma, P (2021) Op cit.
236 Verma, A, Lamsal, K, Verma, P (2021) Ibid.
237 Plummer, D, Kearney, S, Monagle, A, Collins, H, Perry, V, Moulds, A, Mroczka, M, Robertson, J, Smith, T, Trewavas, S, et al (2021) Skills and competency framework supporting the development and adoption of the information management framework (IMF) and the national digital twin. [PDF] CDBB. Available at: www.cdbb.cam.ac.uk/files/010321cdbb_skills_capability_framework_vfinal.pdf
238 University of York (nd) Leading the safe development of autonomous systems. [online] Available at: www.york.ac.uk/assuring-autonomy/ [Accessed 2023].

The university will be providing additional capacity in this area by the 2023 commencement of the MEng course in Robotic Systems; which will again have a formal model on safety assurance. However, capacity is still limited, and cannot support the needs of the future workforce in isolation.

Overall, this shows that the market for such education provision has not become apparent to providers. Further, there is very limited knowledge and skills available amongst providers of the knowledge and skills that need to be imparted to address the educational part of competency for the safe adoption of new technologies such as RAS or machine learning.

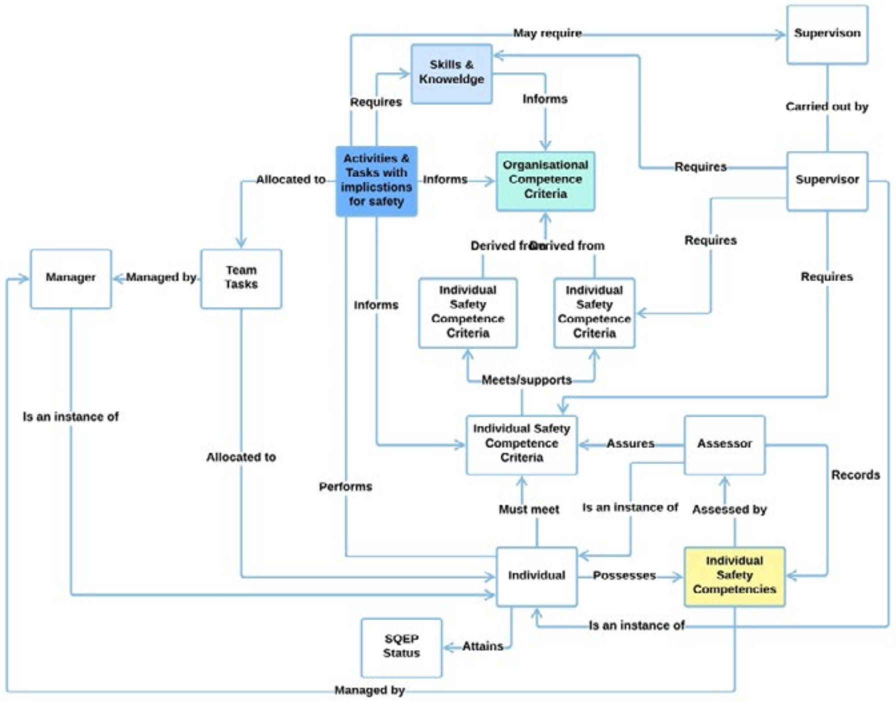
4 Competence framework

Competence frameworks exist for safety in safety critical industries,[239.] yet these frameworks are not designed against the emerging, complex technologies such as AI, ML, or RAS. As such, we have created an illustrative metamodel for a competence framework at Figure 4 which was predicated on the published work by the Institution of Engineering and Technology in the form of their codes of practice for both cyber security and safety,[240.] and for the competence of safety-related systems practitioners.[241.] It can be instantiated and developed by an organisation (regardless of whether they are adopting/planning to adopt emerging technology). Further work would be required to validate and extend this initial proposal.

Our metamodel shows the relationships (may require, requires, informs, performs, managed by, allocated to, is an instance of, attains, assures, requires, carried out by, possesses and records) between the organisational tasks, how they define the required competence criteria, and how this competence is achieved, assured, and allocated across the organisation; culminating in the achievement and management of individual safety competencies, and organisational competence. This metamodel is a generic structure. The elements of the model need to be developed for each new technology. Once the metamodel is instantiated it can be offered to any organisation wishing to safely adopt emerging technology, and facilitates the creation of a bespoke, efficient skills framework. This can then form the basis of a gap analysis for the organisations work force. Further, it can be provided to potential education and training providers to inform their curricula development and offerings to provide initial skills and to update skills for existing staff.

239 IET Standards (2017) Code of Practice: Competence for Safety Related Systems Practitioners. IET Standards.
240 IET (2021) IET Code of Practice: Cyber Security and Safety. [PDF] IET.
241 IET Standards (2017) Op cit.

Figure 4. A metamodel for a competence framework



5 Conclusions

Whilst a plethora of papers, guides etc have been trawled, very little has to date been written on solving the training and education challenges associated with emerging technology in anything but an ad hoc, individualistic manner. Also, we have not found any meaningful recommendations made as to how emerging technology can be safely adopted by organisations. Of the 42 artefacts that were read, only 20 had any relevant information regarding the safe adoption of emerging technology.

We are currently in a steady state of an experience-based approach to assuring safety, and this entire approach is underpinned by appeal to compliance with hard-coded, process-based practice of the type embedded in open standards. Such an approach is challenged by the advent of emerging technology, and a step-wise approach is needed to create the required competencies (both hard and soft skills) required of all stakeholders if we are to ensure the safe adoption of such novel technology. Not addressing the safety skills issue is a significant barrier to gaining the benefits from new technologies.

We need funders, development organisations, regulatory bodies, academia, and educational and training providers to collaborate, and start to consider their current processes, standards, and skills requirements/offerings as a matter of urgency if we are to prevent an impending skills crisis which will prevent the safe adoption of emerging technology. This collaborative work should consider how all stakeholders can combine to:

1. Increase the awareness of the training and education needs of staff involved in the safe adoption of emerging technology, and responsible innovation.
2. Increase research into capability maturity and competency frameworks for safe adoption.
3. Update existing safety competency frameworks and qualifications, such as chartered engineer, to reflect the reality of the competencies required for safe adoption of new technology.
4. Increase the capacity of educational providers in this area.
5. Increase the funding available to deliver pertinent soft and hard skills as a core part of professional and career development.

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