OECD GOING DIGITAL TOOLKIT

POLICY NOTE

Artificial intelligence, its diffusion and uses in manufacturing

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This Toolkit note was written by Alistair Nolan. It was reviewed and declassified by the Committee for Scientific and Technological Policy on 11 May 2021. The note was prepared for publication by the OECD Secretariat.

This Toolkit note is a contribution to the OECD Going Digital project, which aims to provide policy makers with the tools they need to help their economies and societies thrive in an increasingly digital and data-driven world.

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Please cite this publication as:

Nolan, A. (2021), "Artificial intelligence, its diffusion and uses in manufacturing", *OECD Going Digital Toolkit Notes*, No. 12, OECD Publishing, Paris, https://doi.org/10.1787/249e2003-en.

Note to Delegations:

This document is also available on O.N.E. under the reference code:

DSTI/STP(2021)9.

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Using artificial intelligence (AI) and other digital technologies in manufacturing, and other areas of production, is essential for raising labour productivity growth in OECD countries. AI can increase productivity in manufacturing in many ways, from reducing machine downtime to managing supply-chains. However, even in the most advanced economies, the use of AI in manufacturing is limited. This Note discusses the challenges faced by manufacturers in adopting AI and what these imply for the design of policies, including for: skills; institutions for technology diffusion; connectivity; research and manufacturing linkages; computing infrastructure; and, programme evaluation. The Annex provides examples of policy initiatives in a variety of countries.

Using artificial intelligence (AI) and other digital technologies in manufacturing, and other areas of production, is essential for raising living standards and countering declines in labour productivity growth seen in many OECD countries during recent decades. Rapid population ageing – the dependency ratio in the OECD area is set to double over the next 35 years – further highlights the urgency of raising labour productivity. AI can increase productivity in manufacturing in many ways. It reduces machine downtime when intelligent systems predict maintenance needs. AI accelerates industrial research, supports workforce training, helps manage supply-chains and even makes zero-defect production possible in some industries. AI is also enabling increasingly intelligent and collaborative robots that perform work more quickly, precisely and consistently, and raise productivity relative to only-worker and only-robot teams. However, even in the most advanced economies, the diffusion of AI and other digital technologies in manufacturing is slow or partial.

Box 1. What is artificial intelligence?

The term 'artificial intelligence' has many definitions. This paper is based on the OECD definition, which is as follows: "An AI system is a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments. AI systems are designed to operate with varying levels of autonomy."

Source: (OECD, 2019[1]).

This Note examines distinctive features of AI uptake and effects in manufacturing. Because initiatives for diffusing AI in manufacturing are relatively new, this Note also distils a body of OECD and other research on developing and diffusing advanced production technologies in order to draw relevant lessons. A problem common to many public programmes that support technology uptake in manufacturing is the scarcity of robust impact assessment. Accordingly, this Note concludes by considering how to evaluate and learn from the recent initiatives to diffuse AI in manufacturing. This Note complements the *OECD AI Policy Observatory*, which provides information on over 300 national AI policies from 60 countries (including the European Union (EU)).

Uses and effects of AI in manufacturing

Early forms of AI – known as expert systems – have been a part of manufacturing for over 40 years. However, their use was limited to just a few applications, such as process scheduling. Newer types of AI, which learn and make predictions from data, now have a role in every stage of production, including:

- **Industrial Research**. A compelling example comes from Boeing, which recently wished to mass-produce 3D-printed metal parts for jets. However, most useful metal alloys are not printable because the different powder grains do not arrange well. Boeing turned to an AI system belonging to Citrine Informatics. The AI trawled through decades of experiments, scanning 10 million possible recipes for alloy powders. The company wrote software so the AI could even scan data from old reference books and handwritten notebooks. A process of materials discovery that usually takes years was shortened to days (Chen, 2017[2]).
- **Product Design**. AI-driven design software, combined with 3D printing, are set to revolutionise industrial design. Such software generates vast numbers of potential designs. Over many cycles, less suitable designs are discarded and better versions retained and refined. Using such a system, an aircraft bulwark partition incorporated in Airbus' A320 aircraft was stronger than the partition it replaced, but 45 % lighter (Airbus, 2016[3]).
- **Fabrication and assembly**. An important use of AI is in quality control. In the semi-conductor industry, for example, defects in computer chips can appear as irregular shapes on otherwise regular circuit patterns. The irregular shapes attract feature detectors driven by AI.
- **Process control.** So-called 'digital twins' are computer models of a machine, or system of machines, based on real-time data from sensors in real machinery. Aided by AI, the computer models help to monitor production, optimise key parameters and predict maintenance needs.
- **Supply chain management**. BMW has set a goal of knowing the real-time status of all major production equipment at each company producing key components for its vehicles. Information of this sort can extend upstream to the supply of production inputs and downstream to distribution and retail. AI can help to integrate and improve supply chains, for instance by predicting fluctuations in customer demand and efficiently scheduling distribution.
- **Training and cognitive support.** In aerospace, when building its A350 aircraft, Airbus deployed AI to analyse process disruptions. If a worker might encounter an unfamiliar problem, the AI can suggest solutions by analysing a mass of contextual data on similar problems from other shifts or processes. The AI cut time lost to disruptions by a third. (Ransbotham et al., 2017[4]). AI is also enhancing workforce training (using virtual reality) and cognitive assistance (using augmented reality). For example, a technician might see suggested solutions to production problems projected on a safety visor.

- **Other uses of AI in manufacturing.** AI could also create entirely new industries based on scientific breakthroughs enabled by AI, much as the discovery of DNA structure in the 1950s led to the economically important field of industrial biotechnology.

AI can also support generic business functions that matter to manufacturers as well as firms in other sectors. An example is digital security. Digital security incidents appear to be increasing in sophistication, frequency and impact, and have intensified during the Covid-19 pandemic (OECD, 2020[5]). In one incident, in 2014, hackers broke into a German steel mill's office computers and overrode the shut-off mechanisms on the steel mill's blast furnace. Among other advances, the software firm Pivotal has created an AI that recognises when text is likely to be part of a password, helping to avoid accidental online dissemination of passwords.

Many AI-driven social-bots also automate generic tasks such as meeting scheduling (X.ai), business-data and information retrieval (butter.ai) and expense management (Birdly). Lex Machina is also blending AI and data analytics to support patent litigation.

Limited diffusion of AI in manufacturing

Despite AI's promise, adoption in manufacturing is limited. A recent survey of 60 US manufacturers with annual turnovers of between USD 500 million and USD 10 billion found that: "Just 5% of respondents have mapped out where AI opportunities lie within their company and are developing a clear strategy for sourcing the data AI requires, while 56% currently have no plans to do so." (Atkinson and Ezell, 2019[6]). Limited diffusion goes beyond manufacturing: Denmark's information and communications technology (ICT) Use in Enterprises Survey found that 24% of large enterprises used AI in 2019, and just 5% of small firms (Statistics Denmark, 2019[7]). Only around six per cent of all companies in Germany were using AI in 2019 (ZEW, 2020[8]). And a 2017-2018 business survey in the United States, with around 515 000 respondents showed that just 2.2 % of businesses were using machine learning (Beede et al., 2020[9]).

However, AI is sometimes present in manufacturing in ways that are hard to count, for instance in sensor networks deep in machines, or in different types of robot. National Statistical Offices and supra-national statistical agencies – in particular Eurostat – are working to incorporate AI modules into established surveys of business innovation, R&D and ICT use. These initiatives are relatively recent. The OECD's Working Party on Measurement and Analysis of the Digital Economy (WPMADE), along with the OECD's Working Party of National Experts on Science and Technology Indicators (NESTI), closely monitor and provide input to these initiatives.

Obstacles to adopting AI in manufacturing

Uncertainty: Many AI projects involve a degree of experimentation, with no guarantee of success. In this they are unlike standard investments in ICT hardware. The return on investment (ROI) for some AI projects may be particularly hard to estimate *a priori*, in part because the key process of data cleaning involves an element of art. Investment decisions might also have to include complex strategic considerations such as the need for the firm to remain viable in future supply chains.

One international survey of 430 professionals across industry sectors found that 56% wanted more information linking initiatives to ROI (IA Intelligent Automation Network, 2018[10]). Small and medium-size enterprises (SMEs) can generally bear less risk than larger firms. Consequently, uncertain ROIs are a particular hindrance to AI adoption in SMEs in manufacturing, as well as other sectors.

Required accuracy: Manufacturers have greater accuracy requirements for AI systems than firms in most other sectors. Degrees of error acceptable in a retailer's use of AI to improve marketing would likely be intolerable in precision manufacturing, where some processes operate at molecular scales.

Complementary investments: AI is not a plug-and-play technology. An AI project might need to link data silos from different parts of a company. Customer data, for instance, are often separate from supply-chain data. A typical industrial plant might contain machinery of many vintages from different manufacturers, with control systems from different vendors, and all operating with different communication standards. Connecting data silos, and getting machines to communicate seamlessly, may require additional investments in related ICT.

Skills and data: AI skills are almost everywhere scarce. Even leading technology companies often have high vacancy rates for roles requiring AI skills. High salaries available to capable AI researchers are sometimes hard to match in manufacturing. In addition, AI talent is highly concentrated geographically. Just three countries account for half of the AI workforce in Europe: the United Kingdom, France and Germany (LinkedIn Economic Graph, 2019[11]). Within countries, AI skills are also often concentrated in localised hubs (Olander and Flagg, 2020[12]).

"AI" is in fact an umbrella term used for a variety of disciplines including machine learning (ML), image recognition, and natural language processing (Squicciarini and Nachtigall, 2021[13]). Each of these fields requires a significant level of mathematical skill combined with practical experience (typically 10 years or more) before someone is ready to spearhead projects in manufacturing. As a result, talent gaps are even harder to fill when considering specialisms beyond the generic 'AI scientist' (Bergeret, 2020[14]). Because training AI specialists takes years, and demand for AI skills is expected to increase, the scarcity of talent is unlikely to disappear in the near term.

For manufacturers, turning to universities or public research organisations to fill skills gaps is often not a first choice. This can reflect uncertainties about universities' understanding of core business processes and commercial pressures, such as the need to deliver projects to strict deadlines. Uncertainty over ownership of intellectual property (IP) can also be a hindrance. Firms can also seek expertise from consultancy firms. However, for SMEs these services are expensive, and sometimes raise concerns of dependence on the service provider. Some mid-sized and larger industrial companies have created their own in-house AI skills, but this path is generally limited to companies with significant financial and other resources (Bergeret, 2020[14]).

This overall context of uncertainty, required accuracy, need for ancillary investments and skills shortages highlights the possible roles for public, or public-private, initiatives and institutions to help accelerate technology diffusion.

Policies for AI in manufacturing

In general, policies to support the development and use of AI are likely to have high social returns because AI can be widely applied and accelerate innovation (Cockburn, Henderson and Stern, 2019[15]).

This section addresses the following policy and programme-design issues: the focus of national AI strategies; policies on skills and data; the *modus operandi* of institutions for technology diffusion and industrial research; high-speed connectivity; and, policy evaluation. Many other policies – not addressed here – are relevant to wider (and still uncertain) consequences of AI in production. These include policies for competition, and economic and social policies that mitigate inequality. Many of the policy observations considered here – such as on skills and data – are also relevant to other sectors of the economy, both private and public, not considered here.

Good framework conditions will facilitate the wider use of most types of technology, and matter too for spreading the use of AI. OECD analysis highlights the importance of competitive product markets, flexible labour markets, low costs for starting and closing a business, strong contract enforcement, openness to foreign direct investment, trade and internationally mobile skilled labour, and well-developed private equity markets (Andrews and Criscuolo, 2013[16]). These conditions facilitate efficient resource allocation and help incumbent firms and start-ups adopt new technologies and grow.

Initiatives in national strategies

National strategies for AI are relatively new but increasingly widespread. They tend to prioritise a few economic sectors, including logistics, transportation and health. Such strategies often seek to strengthen national AI research and educational capacities, and translate AI research into public and private sector applications.

Some countries include diffusion of AI in manufacturing as one goal of national AI strategies – such as Germany, Japan, Korea, Sweden, the United States and the United Kingdom. However, these are a minority among countries with a national AI strategy, and the strategies in question include many other goals besides.

Bergeret (2020[14]) observes that the priorities in some national strategies may have a 'missing middle', particularly for industrial SMEs that do not operate in the prioritised sectors and are not prime beneficiaries of support for research or new venture funding.

Developing the right skills

A starting point to assist AI uptake in manufacturing is to ensure a solid foundation of science, technology, engineering and mathematics (STEM) skills nationally. In a comprehensive review of STEM education, (Atkinson and Mayo, 2010[17]) identify a series of priorities. These emphasise helping students follow their interests; respecting the desire of students to be active learners; giving opportunities to explore a wide variety of STEM subjects; increasing the use of online, videogame and project-based learning; and, creating options to take tertiary-level STEM courses at secondary level. Since the early 1960s, Japan's Kosen schools have proven the value of such ideas (Schleicher, 2018[18]).

The United States' AI strategy emphasises STEM education. It devotes at least USD 200 million in grant funds per year to promote high-quality computer science and STEM education, including the training of teachers. Finland plans to create new AI Bachelor's and Master's programmes and courses on AI and to promote incentives and training for teachers to use AI in their courses. Many AI strategies also include incentives to retain and attract foreign nationals with AI skills. Belgium, for example, plans to attract AI talent through selective immigration and visa policies.

Targeted skills development

Each year, inflows to the labour force from initial education represent only a small percentage of the numbers of people in work, who in turn will bear much of the cost of adjustment to AI. Both considerations underscore the importance of workforce training. Business and government must cooperate to design training schemes – such as conversion courses in AI for those already in work – with public authorities ensuring the reliability of training certification. Singapore has also developed apprenticeship programs to allow graduate students to learn from AI experts in leading companies in Singapore.

Tooling U-SME – a non-profit organisation in the United States owned by the Society of Manufacturing Engineers – provides comprehensive online industrial manufacturing training and apprenticeships (Tooling University, 2021[19]). A key for policymakers today is to ensure that such programmes include curricula that encompass up-to-date uses of industrial AI (not all of which need to involve programming – see Box 2).

Subnational governments are also implementing AI diffusion initiatives, for instance as part of regional industrial strategies or local SME digitalisation frameworks. Encouraging the development of AI skills, and skills retention, is essential to such initiatives, given the incentives to move to better-paying roles in AI hubs.

Box 2. Not all forms of training need to focus directly on AI and code

Much AI in industry exists in robots. Not all robot-related jobs are programing or software jobs. Many concern hardware. Training could help to open such jobs to workers who possess mechanical skills taught in vocational courses. Many of the necessary skills do not require a 4-year degree. Shorter courses could help, especially if delivered at scale. An example is the intensive 12-week Rockwell programme, in the United States, that provides certification as instrumentation, control and automation technicians.

Source: (Gateway Technical College, 2020[20]).

Skills bridging for AI

Many industrial firms generate a great deal of data but might not have the skills in-house to extract value from the data. In addition, manufacturers are generally product-led, and might have a limited corporate tradition of data analysis (sectors such as finance and marketing have used data analytics for longer). Skills-bridging programmes can help, such as in those operated by the Turing Institute and the Digital Catapult in the United Kingdom (see Annex). These programmes match firms with data that they may not know how to use with experts in AI techniques who demonstrate how the data might be analysed so as to create value. However, among OECD countries such programmes are relatively few. After proper evaluation, policy should consider how to encourage their delivery at scale.

Data policies

Even large industrial firms can fail to exploit the value in their data. By one report, less than 1% of the data generated on oil rigs are used (The Economist, 2017). However, external sources of expertise – including AI start-ups, universities and other institutions – could create value from data held by manufacturers.

To help address the underutilisation of data, governments can act as honest brokers for data partnerships. Among other measures, they can work with stakeholders to develop voluntary model agreements for trusted data sharing. For example, the US Department of Transportation has prepared the draft "Guiding Principles on Data Exchanges to Accelerate Safe Deployment of

Automated Vehicles". The Digital Catapult in the United Kingdom plans to publish model agreements for start-ups entering data partnerships (see the Annex). Korea's AI Open Innovation Hub also provides SMEs and start-ups with data, algorithms and high-performance computing resources to allow them to innovate with AI.

Open government data initiatives usually provide access to administrative and other data that are not directly relevant to AI in manufacturing. Nevertheless, some data can be of value, such as national, regional or other economic data that can help generate demand forecasts. Such forecasts can assist in optimising the flow of inputs and final products in supply chains. Open science, and open data from publicly funded research, can also facilitate the use of AI in industrial research (OECD, 2015[21]; OECD, 2021[22]).

Institutions for technology diffusion

All OECD countries have institutions, policies and programmes with technology diffusion goals. These include universities, professional societies, knowledge exchange instruments (such as innovation vouchers), bodies that provide technical outreach to firms (such as the United States' Manufacturing Extension Partnership programme), applied technology centres (such as Germany's Fraunhofer Institutes), and technology-oriented business services (such as Canada's Industrial Research Assistance Program).

Many countries have also now created institutions and programmes to accelerate diffusion of AI in manufacturing. Various countries have developed programmes to increase the use of AI in manufacturing. For example, Canada has invested CAD 950 million in five regional Innovation Superclusters, one of which focuses on AI for supply chains (SCALE.AI). The AI Accelerator, initiated by Finland's Ministry of Economy and Employment, together with Technology Industries of Finland, spurs AI use in SMEs. Germany's AI Strategy also includes support for SMEs and start-ups through regional AI clusters that foster science-industry collaboration, as well as through AI trainers in Mittelstand 4.0 Excellence Centres (see Annex).

Institutions and programmes to support diffusion can be effective if suitably designed, incentivised and resourced. When effective, they will aid the diffusion of AI in manufacturing. Shapira and Youtie (2017[23]) identifies the main policy considerations:

- Small firms tend to use digital technologies – even mature technologies such as cloud computing – much less frequently than larger firms (OECD, 2019[24]). It is important to systematise key information for SMEs. Germany's Industry 4.0 initiative, for example, has documented over 300 uses cases of applications of digital industrial technologies. It also includes links to sources of expertise (BMWi, 2021[25]). The United Kingdom's 2017 Mayfield Commission led to the creation of an online self-assessment tool. It gives firms a benchmark against best practice, with guidelines on supporting actions (Be the Business, 2021[26]). Information provided through such initiatives should also include AI. Particularly useful is information on ROIs – which most programmes do not provide – along with information on complementary organisational and process changes.

- Because the skills to absorb information are usually scarce in SMEs, simply providing information on technology is not enough. Providing signposts to reliable sources of SME-specific expertise can help. As part of its SMEs Go Digital Programme, Singapore's TechDepot provides a list of preapproved digital technology and service solutions suited to SMEs (IMDA, 2021[27]) (see Annex).
- Technology diffusion institutions need realistic goals and time horizons. Introducing new ways to integrate and diffuse technology takes time, patience and experimentation. Yet many governments want quick and riskless results.
- The aims of technology diffusion institutions must align with their operational realities. If AI has special importance among other technologies, then it might be inappropriate for diffusion institutions to prioritise revenue generation in their funding model. Furthermore, a common problem is to focus on disseminating the most advanced technology, when many enterprises do not fully use even current technologies. With AI, for example, companies often need to implement basic steps in organising the data they have, before anything else.

A generic aim should be to adjust the services that institutions offer, in order to account for specific features of AI, rather than create new institutions. Countries around the globe often accumulate new business support programmes and institutions over time – frequently with little prior assessment of the commercial demand for those services. This can be wasteful and cause confusion for firms.

Policies on connectivity

Manufacturing processes create enormous amounts of data. Access to high-speed broadband is essential. While developments in broadband infrastructure have increased speed in many countries, SMEs are often less likely to be connected to high-speed broadband (OECD, 2020[28]).

Many countries plan or have started to deploy nationwide 5G networks. The United Kingdom's AI strategy mentions public investment of GBP 1 billion to boost communication infrastructures, including GPB 176 million for 5G and GBP 200 million for full-fibre networks. Fibre-optic cable is of particular importance for high-speed connectivity that can facilitate the use of advanced digital technologies in manufacturing. It provides faster access to cloud-hosted information, greater reliability, signal strength, bandwidth, and security properties, as well as a platform for 5G connectivity (see the OECD Recommendation on Broadband Connectivity (OECD, 2021[29]). The lower signal latency it permits is essential for many AI-enabled machine systems and for adopting new technologies such as haptics (which remotely replicate a sense of touch).

AI in manufacturing will require increased use of cloud-based high-performance computing along with data sharing across sites and company boundaries. Machine data and data analytics and even monitoring and control systems will increasingly be located in the cloud. The cloud will also enable independent AI projects to start small, and scale up and down as required. However, the use of cloud computing in manufacturing varies greatly across countries. In Finland, 60% of firms use the cloud, for example, compared to around 16% in Germany (OECD, 2017[30]).

Governments can act to increase trust in the cloud and stimulate cloud adoption. One measure is to help SMEs better understand the technical and legal implications of cloud service contracts. This could include providing information on the scope and content of certification schemes relevant for cloud computing customers.

Linking research and manufacturing

A large part of national AI strategies focuses on R&D. OECD (2017[23]) examines emerging features of industrial research institutions, all of which are relevant to developing AI for, and transferring AI to, manufacturing.

Some manufacturing R&D challenges may need expertise and insight not only from engineers and industrial researchers, but also designers, equipment suppliers, shop floor technicians, and users. Government-funded research institutions and programmes should be free to combine the right partners and facilities to address challenges of scale-up and inter-disciplinarity.

New government-funded manufacturing R&D institutions, programmes and initiatives need to be able to provide innovation support functions beyond basic R&D (e.g. prototype demonstration, training, supply chain development). Test beds can also provide SMEs with facilities to test varieties and novel combinations of equipment, such as AI-driven robots, and in this way de-risk prospective investments. The European Commission is considering development of large-scale AI testing and experimentation facilities, which will be available to all actors across Europe (European Commission, 2020[31]). A number of governments are also experimenting with controlled environments for the testing of AI systems, including by SMEs, for example in Lithuania, New Zealand, the United Kingdom and the United States.

Public funding of AI often goes to public laboratories engaged in long-term research projects, whereas the needs of most SMEs have much shorter time horizons. These laboratories sometimes work with corporations, and occasionally with start-ups. However, many do not focus on solving or improving industry-specific problems. Major R&D programmes for AI also tend to favour large-scale and often transnational industrial corporations, which highlights the possible problem of the previously referenced 'missing middle' in the framework of support. In some cases, R&D-oriented public-private partnerships entail a need for financial resources that exceed the means of SMEs in manufacturing and other sectors.

Some policymakers are taking action to address these issues. Programmes such as InvestEU (see Annex) and Horizon Europe have identified innovation and digital transformation in SMEs as key priorities and are allocating significant funds to this segment of the economy (Bergeret, 2020[14]). Policy can help laboratories working on applied industrial research with financial support and help ease the bootstrap or initial phases of their work, for instance with seed funding, sponsored hiring programs out of university labs, and R&D residency grants. Governments can also use proactive marketing strategies that connect laboratories with SMEs, for instance giving no-cost invitations to events and providing mentions in public communications (Bergeret, 2020[14]).

Developing linkages and partnerships between manufacturing R&D stakeholders is also critical. This reflects the scale and complexity of innovation challenges in advanced manufacturing. Through its *Plattform Lernende Systeme* (Learning Systems Platform), Germany's Federal Ministry of Education and Research brings together expertise from science, industry and society in a forum for exchange and co-operation on technological, economic and societal challenges around AI research and use. Canada's Innovation Superclusters initiative also supports partnerships between large firms, SMEs and industry-relevant research institutions. Denmark's national AI strategy plans a digital hub for public-private partnerships.

Computing infrastructure

Several countries allocate high-performance computing (HPC) resources to aid AI-related applications and R&D. Some are setting up HPCs designed for AI and give financial support to develop national HPC infrastructure.

However, public HPC initiatives often focus on the computation needs of "big science", while HPC, and the AI systems it helps support, is increasingly important for firms in industries ranging from construction and pharmaceuticals to the automotive sector and aerospace. Two-thirds of US-based companies that use HPC agree that: "increasing performance of computational models is a matter of competitive survival" (US Council on

Competitiveness, 2014[32]). Box 3 describes steps governments can take to expand access to HPC for manufacturers.

Box 3. Getting HPC into manufacturing: Possible policy actions

- Raise awareness of industrial use cases, with quantification of their costs and benefits.
- Develop a one-stop source of HPC services and advice for SMEs and other industrial users.
- Provide low-cost, or free, limited experimental use of HPC for SMEs, with a view to demonstrating the technical and commercial implications of the technology.
- Establish online software libraries/clearing houses to help disseminate innovative HPC software to a wider industrial base.
- Give incentives for HPC centres with long industrial experience, such as the Hartree Centre in the United Kingdom (Hartree Centre, 2021[34]), or TERATEC in France (Teratec, 2021[35]), to advise centres with less experience.
- Modify eligibility criteria for HPC projects, which typically focus on peer review of scientific excellence, to include criteria of commercial impact.
- Engage academia and industry in the co-design of new hardware and software, as has been done in European projects such as Mont-Blanc (Mont-Blanc, 2021[36]).
- Include HPC-related education in university science and engineering curricula.
- To lower the cost of using HPC for SMEs in manufacturing and other sectors, explore opportunities for co ordinating demand for commercially provided computing capacity.

Sources: (Hartree Centre, 2021[34]); (Teratec, 2021[35]); (Mont-Blanc, 2021[36]).

Programme and policy evaluation

In terms of financial resources and experts involved, the scale of the diffusion-related elements of national AI strategies is often quite small, even though most national strategies stress the role of AI in business. Without reliable metrics and data on the impact of public support, policymakers have no basis for decisions on whether to maintain, scale up or scale down their initiatives around AI.

Evaluating the impact of a national AI strategy would be challenging conceptually, given the difficulties of establishing counterfactuals across the many types of action that most national strategies comprise. One approach would be to use structured hypothesis testing, carefully selected indicators and creative extrapolation from diverse sources of evidence.

However, generating useful evaluation data is more attainable for some of the individual initiatives that national AI strategies comprise, such as programmes to accelerate diffusion in the business sector. Where appropriate, evaluations should make more use of tools used routinely in other spheres, including randomised control trials and quasi-experimental methods. For example, since 2003, the Abdul Latif Jameel Poverty Action Lab, at the Massachusetts Institute of Technology, has developed into a global network of researchers who use randomised evaluations to measure critical policy interventions in the fight against global poverty. Developing a similar initiative – or initiatives – around public policy towards AI would be helpful.

(Warwick and Nolan, 2014[37]) set out some key considerations on evaluation of industrial policies, all of which apply to public schemes for AI in manufacturing:

- Consider mandating evaluations when public funding is involved. Mandatory evaluation, with funding earmarks, has helped to spur evaluation work.
- Insist on the development of data and evaluation strategies as a pre-requisite for the commencement of programmes. AI strategies typically announce their aims, but not how impacts will be measured.
- Choose the evaluation technique in the light of the size and nature of the programme. Studies of large programmes – especially pilot schemes for programmes that could be rolled out later at larger scale – should use a variety of (data-intensive) methods: random assignment, quasi-experimental assessments, interviews with beneficiaries, etc.
- Commit to transparency and early publication of evaluation findings and their underlying data.
- Ensure mechanisms for policy learning from evaluation findings. While accountability and audit are important, feedback into policymaking is essential.
- Choose the right evaluation metrics. For example, for programmes that support R&D for AI in industry, better evaluation of institutions and programmes may need indicators beyond traditional metrics, such as numbers of publications and patents. These could include, for instance, evidence of successful pilot line and test-bed demonstration, development of skilled technicians and engineers, and SME participation in new supply chains, as a result of adopting AI.

Annex. A selection of policy initiatives for AI diffusion

Demonstration and testing facilities for SMEs – Germany's Centres of Excellence for AI

Responsible entity: Die Bundesregierung, KI Nationale Strategie für Künstliche Intelligenz

Description: An aim of Germany's national AI strategy is to establish supra-regional Centres of Excellence for AI, given that Germany's scientific expertise on AI and its users are found across the entire country. Having a single centralised cluster of excellence for all industries would not fit Germany's distribution of industrial activity. The core business of the centres will be a transfer of knowledge to and close cooperation with industry, specifically to achieve successful commercialisation. It is considered essential that the Centres draw on a broad level of interdisciplinary skills, allowing for the full potential of AI to be harnessed for different applications.

Read more: *https://www.ki-strategie-deutschland.de/home.html*.

Industrial Internet Consortium - Testbeds: Smart Factory Machine Learning for Predictive Maintenance Testbed

Responsible entity: Industrial Internet Consortium

Description: Many existing machine learning technologies can be applied to predictive maintenance, but most are not fully developed to optimize accuracy or performance in order to retrieve actionable insights. Many are able to detect a failure, but do not have the ability to perform specific activities in industrial environments. Founded in 2017, the Smart Factory Machine Learning for Predictive Maintenance Testbed seeks to test algorithms and architecture solutions - such as communication protocols, cloud platforms, cybersecurity, etc. - in real industrial environments.

The Smart Factory Machine Learning Testbed is working on various use cases, such as a Computer Numeric Control (CNC) machine tool used to manufacture crankshafts for the automotive industry. Deployed in three locations, the testbed's first deliverable was published in the IEEE Internet of Things Journal in May 2018 (*https://ieee-iotj.org/*), covering the results of one of the testbed's first dynamic machine learning algorithms use a data stream from an industrial machine.

Read more: *www.iiconsortium.org/news/joi-articles/2019-November-JoI-Smart-Factory-Machine-Learning-for-Predictive-Maintenance-Testbed.pdf*.

AI Sweden : The Swedish National Center for Applied Artificial Intelligence

Responsible entity: Swedish National Center for Applied Artificial Intelligence

Description: Launched in February 2019, AI Sweden is the Swedish National Center for applied Artificial Intelligence. It is supported by the Swedish government and private sector. The overarching aim is to accelerate the use of AI for the benefit of Swedish society and competitiveness, and all initiatives involve collaboration with more than 80 partners. Among other measures, AI Sweden operates a Data Factory to help partners provide and access data, as well as computing power and data storage capacity for AI projects. AI Sweden has offices in Stockholm, Gothenburg, Lund, Örebro, Luleå, Sundsvall, Skellefteå and Linköping. An aim of this wide geographic coverage is to connect the different regional AI-ecosystems to each other, creating a truly national initiative.

Many of the technical challenges that AI Sweden seeks to address relate directly to AI in industry. These include:

- ***Verifiable robustness***: while complex and data-driven systems may perform well on average, they may behave less well, or unpredictably, when encountering unknown situations and data. This is acceptable in situations where the cost of making a mistake such as a wrong classification or prediction is low, but is often unacceptable in industrial (or medical) settings.
- ***Decision making under uncertainty***: to improve the quantification of uncertainty in AI models, whatever their source, and thereby support the best choice of AI solutions in industrial, healthcare and other settings.
- ***Complex systems management*** (machine learning and operations research): to advance the use of AI in making operations and processes more effective, such as better resource use in cloud and telecom systems, and more efficient supply chains and production. The intersection of machine learning and operations research has the potential to make many industries and organisations more efficient, not least medium-sized companies.
- ***Privacy preserving AI***: to develop and understand methods for privacy-preserving data- and model sharing, and disseminate information on legal considerations and best practises in collaborating on and implementing AI solutions.
- ***Decentralised AI – edge and federated learning***: to advance the use of systems that can learn locally using, for example, federated learning techniques.

- ***AI systems, platforms and operations***: to help Sweden use AI at scale and to be relatively independent in terms of systems and platforms, fostering collaboration around AI platforms, operations of AI systems, and processes for building data driven systems.

Read more: *www.ai.se/en*.

Singapore's Triple Helix Partnership

Responsible entity: Singapore Government – Smart Nation Singapore

Description: A centrepiece of Singapore's national AI strategy is to accelerate the uptake of AI in firms. This is to be achieved by: deepening investments in AI-related R&D across the research system; driving partnerships between the research community and industry (over 15 AI public-private partnerships and joint labs have been established to date); accelerating AI adoption through a Digital Services Lab; and, establishing AI innovation testbeds (for example, AISG's 100E Programme helps companies to deploy AI in a co-investment model).

Read more: *www.smartnation.gov.sg/why-Smart-Nation/NationalAIStrategy*.

Bridging Gaps in Expertise: The Digital Catapult and The Alan Turing Institute, United Kingdom

Responsible entities: Digital Catapult, United Kingdom; the Alan Turing Institute, United Kingdom

Description: AI skills are almost universally scarce. At the same time, compared to other sectors such as insurance, manufacturing has traditionally been less data oriented. Two initiatives in the United Kingdom aim to help bridge the associated gaps in expertise and understanding.

The United Kingdom's Digital Catapult Pit Stop activity brings together large businesses, academic researchers and start-ups in collaborative problem-solving challenges around data and digital technologies. Pit Stop events are targeted to the specific needs of different sectors, such as the automotive industry, where common challenges and opportunities lie in connection with AI.

Also in the United Kingdom, the Data Study Group at the Turing Institute, enables major private- and public-sector organisations to bring data-science problems for analysis. The partnership is mutually beneficial. Institute researchers work on real-world problems using industry datasets, while businesses have their problems solved and learn about the value of their data.

Read more: *www.digicatapult.org.uk/events/detc-pit-stop-increasing-efficiency-in-automotive-product-development*; *www.turing.ac.uk/collaborate-turing/data-study-groups*.

Canada's AI-Powered Supply Chains Supercluster (Scale AI)

Responsible entity: Government of Canada

Description: In 2017, the Government of Canada engaged Canadian firms of all sizes and other innovation actors, including post-secondary and research institutions, to propose strategies aimed at creating major clusters of innovation. In 2018, the business-led Scale AI initiative was named as one of five superclusters to receive federal government support. Based in Quebec, spanning the Montreal-Waterloo corridor, the Scale AI innovation supercluster will receive total federal funding of up to CAD 230 million (USD 183 million). Scale AI has aimed to bring together firms in the retail, manufacturing, transportation, infrastructure and information and communications technology sectors to create AI-enabled supply chains. More specifically, the initiative's goals are to:

- Create productivity gains across industries through AI-enabled supply chain optimization;
- Generate AI-powered supply chain intellectual property (IP) and new business opportunities;
- Strengthen supply chains through innovation and the integration of AI in products and services; and,
- Promote responsible use and development of AI-related technologies.

The initiative has five main programmes, which among other things will; facilitate commercialisation of AI-enabled supply chain solutions; assist SME and start-ups to scale-up and grow as AI products and services providers, for instance through incubation and mentorship programmes, as well as networking; improve the level and diversity of AI skills and strengthen linkages between academia and industry; and encourage collaboration, data sharing, access to IP, and other synergies.

Read more: *www.ic.gc.ca/eic/site/093.nsf/eng/00009.html*.

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