Contents

Executive Summary

1. Introduction 6
   1.1 Industrie 4.0

2. The role of data analytics and decision making in the development of future industrial systems 7
   2.1 Data Analytics
   2.2 The future of Advanced Data Analytics
   2.3 Data Analytics for Decision Making

3. Industrial Digital Technologies for Industry – how can they support Data Analytics and Decision Making? 9
   3.1 Industrial Internet of Things
   3.2 Computing supported decision-making – big data and artificial intelligence.
   3.3 Artificial Intelligence and Machine Learning
   3.4 Data Visualisation

4. Maximising the true value from data to achieve optimisation in industrial systems 11
   4.1 The Value from Advanced Data Analytics and Optimisation

5. Current Research Portfolio under the Thematic Area 12
   5.1 EPSRC funding
   5.2 Innovate UK funding
   5.3 EU funding

6. Research Leaders in Manufacturing Data Analytics 15
   6.1 Universities
   6.2 Catapults

7. Industrial Leadership 16

8. Research opportunities for data analytics and decision-making for future industrial systems 17
Figure 1. The Word cloud created from participant’s definition of Autonomy in a manufacturing context (EPSRC Autonomous Manufacturing Workshop Report, 4th September 2014)
Data analytics and decision making for industrial systems needs to respond to the rapid growth in, and collection of, vast amounts of data. This has come through the drive towards digitising manufacturing, the Industrial Internet of Things, wireless high-speed factory connectivity and hardware like miniaturised sensors and processing power.

The most transformational industrial digital technologies (IDTs) currently directly influencing data analytics and decision-making are Artificial Intelligence, the Industrial Internet of Things and Data Visualisation including Augmented and Virtual reality.

Parallel developments in computing capabilities with powerful and cheap processing, low cost data storage and cheaper components - changes which are also disrupting the data analytics landscape.

A step change in the development of these IDTs alongside cheap data storage and enhanced processing capabilities, the value from the data has the potential to be fully realised in future industrial systems.

We know there is a strong necessity to increase productivity because of the anticipated need to lower selling price, as industrial systems are increasingly entering into and operating within a new, more competitive international market.

We also recognise that there is the common necessity to embrace automation through data analytics to boost productivity - a move that would be crucial to support transformative and sustainable change in industry.

UK manufacturing needs to operate in a market that is profitable, with low volume, flexible processes in contrast to the mass production market currently dominated by Asia for example. The UK must move towards advanced data analytics and decision making with as fully autonomous a value chain as possible to accomplish this.

Current research has already recognised this, and advanced data analytics using Artificial Intelligence has become a strong UK focus and future goal. Robotics and Artificial Intelligence has also been a focus to date and Government is supporting the research, development and innovation landscape by making Artificial Intelligence a UK Grand Challenge alongside the new Sector Deal for Artificial Intelligence.

Furthermore, the current UK industrial digitalisation landscape is well summarised by the Made Smarter Review\(^a\), published in 2017 which highlights UK strengths in AI, Machine Learning and Data Analytics. The report proposes a series of recommendations, which could support the goals of Connected Everything and this Thematic Area and in particular recommends the creation of a Digital Research Centre focused on AI, Machine Learning & Data Analytics.

Professor Dame Wendy Hall and Jérôme Pesenti’s review\(^b\) on how the Artificial Intelligence industry can be grown in the UK laying out its vision to make the UK the best place globally for businesses developing and deploying AI to start, grow and thrive.

In reality, Artificial Intelligence is being adopted by larger organisations to analyse data leading to the optimisation of operations across the entire organisation. This is enabling a reduction in costs, increased efficiency and resource management, as well as increased productivity and ultimately increase the competitiveness of the business. It is widely acknowledged that this level of adoption is currently insufficient, particularly amongst SMEs, to ensure that the UK remains globally competitive.

This report concludes that whilst the UK is taking powerful steps to tackle the data analytics and decision- making theme, and we have some strong industry and academic leadership, work still needs to be done to ensure we can truly benefit as an industrial nation from the digitisation of data.

---


The report identifies some research challenges for the shorter and longer term, if we are to fully realise the value of the data being produced and to wholly enable robust, credible and usable decision-making in future industrial systems.

This report is a synthesis of publicly funded research being undertaken in the UK and has been led by a team, the Institute of Industrial Research, University of Portsmouth, who have been working in data analytics and decision-making for over 15 years.

Compilation of this report has involved considerable desk-based research and analysis of the publicly available data on research activities being undertaken in the UK. It has also involved engagement with actors in the manufacturing sector and the wider supply chain. The aim has been to understand current data analysis activities better, to identify any gaps in research as well as to seek out examples of industrial leadership in this area.
1. Introduction

Manufacturing contributes £6.7 trillion to the global economy. Contrary to widespread perceptions, UK manufacturing is strong making up 10% of Gross Value Added (GVA) and 45% of UK exports. Despite the decline since the 1970s, when manufacturing contributed 25% of UK Gross Domestic Product (GDP), the UK is currently the ninth largest manufacturing nation in the world.\(^d\)

In addition, according to EEF\(^e\), UK manufacturing currently:

- represents 68% of business research and development (R&D)
- provides 14% of business investment

EEF also states that “although the contribution of manufacturing to GDP has declined on paper, many of the services provided to manufacturers which would have once been considered part of manufacturing – such as catering; cleaning; building services, security and so on – are now allocated into different areas of the economy”.

They argue however, that those kinds of activities and contributions are actually directly reliant on manufacturing for continued business and therefore could actually be considered as a part of manufacturing’s GDP input meaning an increase of GVA to 19%.

Taking into consideration the Made Smarter Review\(^a\) definition of industrial systems to include asset-intensive industries such as utilities (e.g. oil production) together with the manufacturing as a service market one can conclude that the actual GVA figure for the UK industrial sector is undoubtedly higher.

In addition, also quoted in the Made Smarter Review\(^a\), is the potential impact of what are referred to as Industrial Digital Technologies (IDTs) on aspects of the industry such as productivity, international competitiveness, the job market, the strengthening of the supply chain, increased exports, improved resources efficiency.

The review estimates that this impact could be as much as £455 billion for UK manufacturing over the next ten years leading to an increase in manufacturing sector growth of up to 3%, a net gain of over 175,000 jobs and a reduction of 4.5% in CO2 emissions.

One such IDT is defined as Artificial Intelligence, machine learning and data analytics and the projected growth to be delivered by AI could add an additional £630bn to the UK economy by 2035, increasing the annual growth rate of GVA from 2.5 to 3.9%.\(^b\)

Indeed, the UK’s Industrial Strategy quotes a McKinsey Study\(^f\) that asserts that “Embedding AI across UK (including industry) will create thousands of good quality jobs and drive economic growth...[and] create a net total of 80,000 new jobs annually in the UK and a Pricewaterhouse Coopers (PwC) report\(^g\) that found AI could add £232bn to the British economy by 2030.

1.1 Industrie 4.0

The thematic area itself was identified through discussions in the network but firmly has its origins in the original German model, Industrie 4.0 (I4.0) whose key design principles have been distilled by some to show the I4.0 Key Design Principles for Smart Factories:

- Interoperability - The ability of humans sensors and machines and other devices to communicate with each other via the ‘Internet of Things’
- Information Transparency – The creation of a virtual model of physical systems through sensor data, which requires extensive interpretation or raw sensor data
- Technical Assistance – The ability to provide relevant information to humans by amalgamating data from multiple sources and visualising it. Additionally, the ability

---

\(^a\) EEF UK Manufacturing Statistics
https://www.themanufacturer.com/uk-manufacturing-statistics/

\(^b\) EEF UK Manufacturing 2017/18, The Facts

https://www.mckinsey.com/~/media/

\(^d\) Pricewaterhouse Coopers (PwC), The economic impact of artificial intelligence on the UK economy, 2017
https://www.pwc.co.uk/economic-services/assets/ai-uk-report-v2.pdf
executes tasks that humans find dull, dirty and dangerous.

- Decentralised Decision – The ability to make routine decisions on their own with high level automation

These principles have their roots within the high-tech strategy project conducted by the German government in 2012 that sought to promote computerisation within manufacturing. It became apparent that communication or connectivity, the ability to collect, handle and process data, the importance of data visualisation for human decision-making and then automation were key aspects to consider in the move towards I4.0 or digitising manufacturing.

This report has also sought to consider the framework surrounding data analytics, and in particular advanced data analytics, in order to recognise the value of data to industry and how this has enabled the decision-making process to become central to the data analytics landscape.

Additionally, the report has aimed to consider the role of the IDTs in this area as well as big data, looking at past and current research projects before finally looking to the future to identify research opportunities in line with industry requirements and in partnership with academic and industrial leaders within the advanced data analytics and Artificial Intelligence landscape.

This report, then whilst a synthesis of publicly funded research being undertaken in the UK, is also aiming to explore the opportunities and challenges that future industrial systems may face and therefore has focused on addressing the following three questions:

1. What is the role of data analytics and decision making in industrial systems?

2. How can industrial systems take advantage of Industrial Digital Technologies – in this case, IoT, Artificial Intelligence and Data Visualisation?

3. How can UK industry maximise the true value from data to achieve optimisation in industrial systems?

2. The Role of Data Analytics & Decision Making in Industrial Systems

2.1 Data Analytics

Data Analytics is a discipline that has been around for many years and since the 1960s has been used as operational support in industry. In the last decade a common classification of the types of data analytics has emerged and the academic community has also taken time to consider how data analytics is evolving and what it means for the end user. In generic terms, there are four distinct categories as defined by Gartner (2014): Descriptive, Diagnostic, Predictive and Prescriptive (see Figure 2).

![Figure 2. Four categories of Data Analytics](source)

Descriptive analytics is the examination of data or content, usually manually performed, to answer the question “What happened?” (or “What is happening?”), characterised by traditional business intelligence (BI) and visualisations such as pie charts, bar charts, line graphs, tables, or generated narratives.

Diagnostic analytics is a more advanced form of analytics which examines data or content to answer the question “Why did it happen?”, and is characterised by techniques such as drill-down, data discovery, data mining and correlations. You can see how the human input in this type of analytics remains high.

Predictive Analytics is an even more advanced analytics as it seeks to predict the future, answering the question “What is going to happen?” or more precisely, “What is likely to happen?”. It is characterised by techniques such as regression analysis, forecasting, multivariate statistics, pattern matching, predictive modelling, and forecasting; this is where Artificial Intelligence begins to play a significant role in more advanced data analysis.
Finally, Prescriptive Analytics is seen as the most advanced form of analytics in this model as it uses the data to **optimise** decision making. In other words to answer the question “What should be done?” or “What can we do to make X happen?”

Gartner’s definition states it is characterised by techniques such as graph analysis, simulation, complex event processing, neural networks, recommendation engines, heuristics, and machine learning. It is also clear that human input for this type of analytics, according to Gartner has been removed entirely and the analytics has fully embedded and automated the decision-making – Industrie 4.0’s decentralised decisions principle.

2.2 The future of Advanced Data Analytics

Published in 2017 in Elsevier and entitled “Critical analysis of Big Data challenges and analytical methods” a slightly different model is outlined, focusing heavily on the **business impacts** of data analytics or what could be referred to as industrial analytics. This paper firmly places the data analysis debate in a business setting, moving on from Gartner’s more detached terms as described above.

The paper begins with the same category of descriptive analytics, but then moves to **inquisitive analytics** which is similar to diagnostic analytics as it is probing of the data to certify/reject business propositions, for example, analytical drill downs into data, statistical analysis, factor analysis.

Predictive analytics in the paper is similar to Gartner’s description and there is also Prescriptive analytics – again referring to optimisation but also included randomised testing to assess how businesses enhance their service levels while decreasing the expenses.

The authors then posit an additional new category, **pre-emptive analytics** which focuses on “having the capacity to take precautionary actions on events that may undesirably influence the organisational performance”. Perhaps this could also be considered as building resilience into an organisation.

This second model, then, begins to overtly link business value with data analytics, something which other commentators have noticed as not overtly addressed in the Gartner model. This draws attention to the real reasons that data analytics is so crucial – the ability to give insight that can increase revenue for example, through upgrading existing products, changing or creating new business models or cost cutting. In essence, the decision-making.

According to the Industrial Analytics Report 2016/17, it is the latter types of analytics where industry is seeing most interest and value – predictive maintenance for example as well as customer/marketing related insights and also analysis of customer product usage in the field. This reflects Gartner’s assertion that there is a move towards more advanced analytics coupled with an increased importance in industrial analytics for **business intelligence** is set to increase sharply going forward.

2.3 Data Analytics for Decision Making

What is most crucial in this discussion, then, is the enhanced insight and decision-making aspect of data analytics. Businesses use the data to understand more: to move beyond **hindsight**, into **insight** and then beyond **insight**, into **foresight**.

Last year *The Manufacturer* published findings from a study into how the use of big data and analytics is set to transform high value manufacturing. The report was carried out by Warwick Analytics on behalf of The Alan Turing Institute (ATI) and collated the views of almost 50 senior industrial executives within predominantly UK-based high value, global manufacturing companies.

The study highlighted the seven areas where data analytics could have a significant impact, as it acknowledged that the ability to “extract meaningful insights about products; processes; production; yield; maintenance, and other manufacturing functions, as well as the ability to make decisions

---

1. Industrial Analytics Report 2016/17


---

and take proactive action – when it matters – can deliver tremendous growth and profitability results”.

Seven areas where data analytics could have significant impact.

1. Improving quality
2. Improving yield
3. Improving warranty & customer services
4. Increasing production throughput
5. Speeding up time to launch
6. Predicting &/or preventing maintenance
7. Improving or maintain supply chain operations

The study concluded that “combined, these facts mean that advanced analytics can become a powerful, strategic weapon for supply chain optimisation”.

3. Industrial Digital Technologies for Industry – how can they support data analytics and decision-making?

Whilst Data Analytics then is advancing in terms of its ability to support decision-making, it is important to identify the industrial digital technologies that will support the growth and adoption of data analytics and decision-making; technologies that are shaping its further evolution.

3.1 Industrial Internet of Things (IIoT)

The Internet of Things (IoT), because of its enormous data sets, time-stamp storage, and real time or near real time data streaming is posing an additional challenge to data analytics as cheap sensors push data through for processing and analysing in a way never experienced before. In industry, the Industrial Internet of Things (IIoT) is about connecting machines to machines, and using sensors along with other technologies such as Artificial Intelligence, miniaturised data collection units and onsite processing to enable data to give near real time insights that can add value to the business.

According to an IDC Forecast report, the global market value of IoT is projected to reach $7.1 trillion by 2020 and therefore IIoT is going to play a significant role in the development of data analytics and decision-making going forward.

IoT is closely linked to the necessary connectivity or interoperability required by I4.0 and does support the collection of data from multiple sources that need to be brought back together on a smart platform that can integrate data from different sources in order to support decision-making.

This interpretation and processing of the raw sensor data is a key aspect of data analytics.

Digital Twin Technology

Digital Twin technology is also an aspect of IoT which requires machine learning in order to develop a virtual model of a process, product or service by way of the sensor data— what I4.0 might refer to as information transparency.

By conjoining the pairing of the digital (data) and physical (e.g. machines) with advanced data analytics one can easily monitor systems and use simulations to predict and even pre-empt challenges, turning them into opportunities.

Data Fusion

Data Fusion will also be a key aspect of IoT as data is derived from diverse and dispersed sources and turned into information and knowledge in order to make informed decisions.

High Level Data Fusion, where data analysis is required as part of the fusion process, will demand advanced data analytics for decision-making.

3.2 Computing supported decision-making — big data and Artificial Intelligence.

It is clear, then that the data needs to be ever more processed as you progress through the analytics models in order to achieve the predictive and prescriptive and even pre-emptive analytics that industry needs to adopt.

\[k\] See [https://www.idc.com/research/container_error.jsp](https://www.idc.com/research/container_error.jsp)
Gartner’s definition of Big Data is as follows: “Big data” is high-volume, -velocity and -variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making.”

Consider how industrial digital technologies become ever more important alongside the diminishing role of human input in decision-making in data – a shift surely linked to the 3 Vs - volume, velocity and variety. Now data is so plentiful, coming from so many sources, and at such high speed with constant change as well, it is virtually impossible for humans to process and make decisions without help.

The innovative forms of information processing, which are really coming through the technologies (of which AI is one of many) that are capable of storing, processing, linking and managing fluctuating data sets from different origins and of different types in order to perform some kind of comprehensive analysis, have and will continue to play a role in the development of data analytics.

With the real opportunity offered by these technology advancements, fast sampling sensors systems, the miniaturisation of embedded data collection units and the development of powerful onsite processing, there is now real opportunity to enable decision making sometimes within milliseconds, which will enable organisations to make smarter, quicker and more accurate decisions.

### 3.3 Artificial Intelligence and Machine Learning

Fully decentralised decision-making or automation requires that upper level of data analytics described as prescriptive.

Artificial Intelligence and machine learning become ever more fundamental to future industrial system, as they are industrial digital technologies that will enable advanced and complete decision-making from data.

Artificial Intelligence is the broader concept of machines being able to carry out tasks in a way that we would consider “smart”, whilst machine learning is a method of data analysis that automates analytical model building. Neither term is new, and both techniques have been developing since the 1950s.

However, as technology has progressed and computing power has improved dramatically, the opportunities posed by big data, alongside advancement of parallel processing with multi cores and vast amounts of cheap data storage have meant increased interest in Artificial Intelligence to really make use of the data that is being made available.

#### Machine Learning

Using algorithms that iteratively learn from data, machine learning allows computers to find hidden insights without being explicitly programed where to look. With the arrival of “big data” the ability to automatically apply complex mathematical calculations to big data – over and over, faster and faster – is a recent development that, coupled with growing volumes and varieties of available data, computational processing that is cheaper and more powerful, and affordable data storage, is leading to quicker and smarter ways to use data to make robust and accurate decisions.

And this is where deep learning, defined as a subfield of machine learning that is concerned with algorithms inspired by the structure and function of the brain called artificial neural networks, can really now become powerful. The data is more readily available, the data sets larger and computer processing power great and this is enabling data scientists to run more complex models of these artificial neural networks and in so doing achieve considerable advances in image and speech recognition.

Artificial Intelligence and machine learning tools need to build knowledge from the data – knowledge that will be required in the future – for example to build resilience into the business model, to enable long term sustainable industries, and to convert digitised data into information that could, for example, inform and improve engineering design.

### 3.4 Data Visualisation

Crucial here then, is the need to allow the relevant data and information to be visualised in a way that can enable humans to make decisions. – the I4.0 key design principal of technical assistance.

---

1 See [https://www.gartner.com/it-glossary/big-data](https://www.gartner.com/it-glossary/big-data)
Perhaps some of the less appropriate or more mundane tasks will be executed using prescriptive data analytics, but there will always be a need for decision makers to interpret the data in a way that is meaningful and useful. Data visualisation will be key in this aspect of analytics where decentralised decisions or automation has not been fully achieved throughout the value chain.

Data Visualisation tools don’t just display data, they enable a better understanding of complex data sets by pictorially displaying patterns, general concepts, evolutions, and trends. Without data visualisation some data may never be actionable as, without the tools, it would be impossible to display large and complex data sets.

At the same time data visualisation is vital to simplify the data and its insights, compartmentalising them into digestible “chunks” of knowledge or intelligence. Data Visualisation also enables teams of colleagues to work together with the data, leading to collaborative ways of working together to solve problems, develop strategies and make decisions. It also, interestingly, enables the faster visual cortex of the brain to respond allowing the information to be processed faster and thus delivering a quicker response time for decision making.

Virtual Reality (VR) and Augmented Reality (AR)

Whilst VR and AR are typically technologies associated with the gaming and entertainment sector, the growth of digitised data is calling for more advanced ways to not just read the data but also interact with it, and manipulate it.

More than that, VR can also help to stimulate other senses and make interaction with data immersive, ensuring focus on the data itself for quicker and more productive interactions and consequent decision-making.

To be able to see multi-dimensional data sets could also bring new insights, and by being a collaborative and digital medium it also enables simultaneous use by multiple decision makers, making it a more dynamic and progressive visualisation tool.

4. Maximising the true value from data to achieve optimisation in industrial systems

To truly remain competitive globally and to ensure that we are as efficient and productive as possibly going forward, it is the shift towards prescriptive and pre-emptive data analytics that needs to take place.

We must, then, use the data not only to predict the future but also do things better, more efficiently and to make the best or most effective use of (a situation or resource). We must use data ultimately to optimise the way we work now and in the future.

In manufacturing, this optimisation should be taking place right across the organisation in question, arguably across the industry in its entirety, and therefore data analytics and decision making begins to have impact and increase value through the value chain – from the supply chain, into the governance of the data and its security, through to services and customers. Indeed, one could see data analytics’ true value also being found in the interoperability of the platforms and controls systems through scheduling, monitoring (not just predictive maintenance) and even design. The notion of the smart, connected factory will require real time responsive analytics throughout the entire industrial system, both internally (the factory itself) but also externally (customers, supply chain).

4.1 The Value from Advanced Data Analytics and Optimisation

A true, quantifiable value of Data Analytics and Decision Making to UK manufacturers or to the broader theme of Industrial Systems is hard to define.

However, according to two reports: The value of big data and the Internet of Things to the UK economy by the Centre for Economics and Business Research (CEBR) and SAS™ the global leader in analytics software and services and the former CEBR’s 2012 report, Data equity: Unlocking the value of big data, figures have been derived to

---


Centre for Economics and Business Research (CEBR). Data equity: Unlocking the value of big data, 2012


---

\[\text{Report for SAS: The value of big data and the Internet of Things to the UK economy, Centre for Economics and Business Research, 2016} \]

\[\text{Centre for Economics and Business Research (CEBR). Data equity: Unlocking the value of big data, 2012} \]
forecast the contribution of big data analytics adoption to the UK economy from 2012 to 2017:

“Big data analytics is estimated to contribute an average of £40 billion per year to the UK economy from 2015 to 2020 (a cumulative value of £241 billion between 2015 and 2020)”. In the earlier CEBR report, the value of data equity was estimated at £12 billion or 0.7 per cent of GDP in 2012. Following the latest research, the figure is expected to rise to £46 billion in 2020 or 2.2 per cent of GDP – nearly four times the original value. The total data equity benefits come from efficiency savings of £220 billion, followed by £12 billion from innovation and £8 billion from business creation.

The industry expected to accrue the greatest economic benefit from big data is manufacturing. The £57 billion boost to this industry over the period 2015-2020 is expected to be driven by the diversity of firms in the industry and the variety of areas in which efficiency gains can be achieved through the use of big data and big data analytics. For example, it could lead to improvements in supply chain management and enhancements in customer intelligence.”

We have already heard how “The UK economy could benefit from an estimated £630bn provided the government supports efforts to develop and apply Artificial Intelligence in a range of applications including healthcare”.

Pricewaterhouse Coopers (PwC) estimates that UK GDP will be 10.3% higher in 2030 as a result of Artificial Intelligence – the equivalent of an additional £232bn – making it one of the biggest commercial opportunities in today’s fast changing economy but it does also stress that “the main contributor to the UK’s economic gains between 2017 and 2030 will come from consumer product enhancements stimulating consumer demand (8.4%).”

5. Current Research Portfolio under the Thematic Area

5.1 ESPRC funding

To better understand current fundamental research activity under the Data Analysis theme, we listed which EPSRC funded projects were applicable (see Table 1). Impact will come from next stage projects as funded by Innovate UK and others. British industry needs this impact.

5.2 Innovate UK funding

Since 2004 Innovate UK has invested in over 31,000 projects across a wide range of areas. Since 2016 Innovate UK has streamlined their process and there are now only five thematic competitions at present:

- Emerging & Enabling Technologies
- Health & Life Sciences
- Infrastructure
- Materials & Manufacturing
- Open Competition

The latest Materials & Manufacturing Round 3, for example, allocated £18.4 million R&D competition to 130 businesses and organisations across the UK that have been funded for 63 projects.

Innovate UK provide a comprehensive spreadsheet listing all funded projects since 2004 and of those listed when searching under Project Title for “data analytics”, 87 projects were identified across all 5 competition areas.

Whilst Innovate UK projects are more Research & Development than pure research, an overview of their activity does highlight areas where industry is innovating and applying data analytics and decision-making. An exciting recent announcement a formal collaboration between the Turing and Digital Catapult, which will support start-ups and scale-ups in London to develop data challenges for researchers. Along the same lines is the funding offered by The Institute of Industrial Research in Portsmouth offers funding for SME’s to explore their data needs in Connected Manufacturing.
### Table 1: Funded research projects of relevance to the theme of Data Analytics and Decision Making

<table>
<thead>
<tr>
<th>Network Plus Feasibility studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular 4.0: Digital Intelligence to Enable a Circular Economy. Cranfield University. £74,529.00</td>
</tr>
<tr>
<td>Towards Additive Manufacturing Process Control Using Semi-Supervised Learning. University of Liverpool. £76,546</td>
</tr>
<tr>
<td>Digitisation of Collaborative Human-Robot Workspaces. Loughborough University. £86,588.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Major awards through targeted calls</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP/K018191/1 - Knowledge Driven Configurable Manufacturing (KDCM)</td>
</tr>
<tr>
<td>EP/K019368/1 - Self-Resilient Reconfigurable Assembly Systems with In-process Quality Improvement. £2,002,994.00</td>
</tr>
<tr>
<td>EP/N018427/1 - Autonomous Inspection in Manufacturing &amp; Remanufacturing (AIMaReM). £1,988,392.00</td>
</tr>
<tr>
<td>EP/L015692/1 - EPSRC Centre For Doctoral Training In Statistics &amp; Operational Research In Partnership With Industry (Stor-I). £ 3,878,130.00</td>
</tr>
<tr>
<td>EP/L015803/1 - EPSRC Centre for Doctoral Training in Industrially Focused Mathematical Modelling. £4,292,330.00</td>
</tr>
<tr>
<td>EP/L016710/1 - EPSRC and MRC Centre for Doctoral Training in Next Generation Statistical Science: The Oxford-Warwick Statistics Programme. £4,263,185.00</td>
</tr>
<tr>
<td>EP/L015129/1 - EPSRC CENTRE for DOCTORAL TRAINING in Financial Computing &amp; Analytics (covering Computational finance, Financial ICT, Regulation, Retail). £ 4,160,711.00</td>
</tr>
<tr>
<td>EP/L016117/1 - EPSRC Centre for Doctoral Training in Web Science Innovation. £3,618,520.00</td>
</tr>
<tr>
<td>EP/L016427/1 - EPSRC Centre for Doctoral Training in Data Science. £4,726,271.00</td>
</tr>
<tr>
<td>EP/L016656/1 - EPSRC Centre for Doctoral Training in Future Communications 2: Training Tomorrow's Internet Innovators. £3,034,323.00</td>
</tr>
<tr>
<td>EP/L015358/1 - EPSRC Centre for Doctoral Training in Cloud Computing for Big Data. £3,503,438.00</td>
</tr>
<tr>
<td>EP/K035606/1 - Oxford University Centre for Doctoral Training in Cyber Security. £3,662,582.00</td>
</tr>
<tr>
<td>EP/K035584/1 - Centre for Doctoral Training in Cyber Security at Royal Holloway. £3,793,546.00</td>
</tr>
</tbody>
</table>
5.3 EU Funding

EU funding for Industrial Systems of the Digital Age, sits under the banner Factories of the Future, which is a public-private partnership (PPP FoF based on research and development activities to help European manufacturers cope with international competition. The PPP does this by supporting the development of key generic technologies and increasing their uptake in European factories. PPP FoF calls for proposals have been published and 150 high level projects were funded under FP7 between 2007 and 2013, to counteract the decline in the manufacturing sector across Europe. The latest Cordis list\(^p\) shows 142 FoF projects involving UK partners.

In addition, the European Factories of the Future Research Association (EFFRA), which exists as a non-for-profit, industry-driven association to promote the development of new and innovative production technologies, has published some recommendations.

The partnership has brought together private and public resources in order to create an industry-led programme for research and innovation with projects producing demonstrators and models to be applied in a wide range of manufacturing sectors.

In a report published in 2016 entitled Factories 4.0 and Beyond it proposes recommendations for the 2018-2020 work programme in which it includes Interoperable Digital Manufacturing Platforms of which Multiple Source (Big) Data Mining and Real Time Advanced Analytics at the Factory and Value Network Levels is an identified work package. Here they stress the need for algorithms that adapt reliably according to constant changes of states and that are capable of predicting all kinds of behaviour that enable true condition based or predictive maintenance. They also ask that the work package delivers in terms of product quality and that the impact must include real time analytics along the whole lifecycle and value chain.

I4MS (ICT Innovation for Manufacturing SMEs) is the initiative promoted by the EC to support the European leadership in manufacturing through the adoption of ICT technologies. In fact, Europe’s competitiveness in that sector depends on its capacity to deliver highly innovative products, where the innovation often originates from advances in ICT.

Therefore, I4MS aims at promoting leading edge technologies, developed in FP7 large ICT projects, in the following areas:

- Robotics
- HPC cloud based simulation services
- Laser based applications
- Intelligent sensor-based equipment

Only one project was revealed under the same search of “data analytics” in the Project Description.

This project entitled Fortissimo is focused on Infrastructure and Services for Simulation and Modelling and is described as follows: “Fortissimo 2 will drive the uptake of advanced modelling simulation and data analytics by European engineering and manufacturing SMEs and mid-caps. Such an uptake will deliver improved design processes better products and services and improved competitiveness”.\(^q\)

\(^p\) See https://cordis.europa.eu/
\(^q\) See https://www.fortissimo-project.eu/about/fortissimo-2
6. Research Leaders in Manufacturing Data Analytics

6.1 Universities

The UK has strong capability in the area of data science and according to the recent Wendy Hall report “The pioneering British computer scientist Alan Turing is widely regarded as launching and inspiring much of the development of AI. While other countries and international companies are investing heavily in AI development, the UK is still regarded as a centre of expertise, for the present at least.”

Indeed other reports, including the recent Made Smarter Review, concur stating that the UK is the leading European country for AI (see Figure 3). The Alan Turing Institute made up of the University of Cambridge, University of Oxford, University of Bristol, University of Bath, and University of Manchester are also academic leaders in this area.

Figure 3. European Artificial Intelligence Landscape

Sheffield University and Imperial also have Machine Learning research groups and there is a growing number of additional Universities (York, Bath, and the City of London) now offering MSc courses in Machine Learning.

The research activity in data analytics and decision-making that is specifically exploring future industrial systems is less clear but we do know that AI has been part of the UK industrial landscape since the 1950s. There are also well established areas of AI academic research on machine learning with particular focus on industrial systems e.g. predictive maintenance such as the University of Portsmouth’s Institute of Industrial Research, Cranfield University and others.

6.2 Catapults and Industrial Research Organisations

More commercially focused R&D activity is certainly taking place and we know that the High Value Manufacturing Catapult network is actively working manufacturing businesses of all sizes and from all sectors to help them turn ideas into commercial applications by addressing the gap between technology concept and commercialisation. How much of this activity focuses specifically on data analytics is not easy to define, though it is clear there is a consistent focus on digital manufacturing. We know, for example, that the Manufacturing Technology Centre (MTC) specialises in manufacturing technologies and processes that are particularly important to the high value manufacturing sector and specifically is addressing Intelligent Automation & Manufacturing Simulation and Informatics as part of its offering. MTC have also been active in the Factories of the Future I4MS programme.

The Advanced Manufacturing Research Centre (AMRC) has a Manufacturing Intelligence team which has the capabilities and expertise to develop numerical and simulation models to support projects and research in operations planning, facilities planning, supply chain modelling, cost analysis and trade-off analysis.

The National Composites Centre has a Digital Manufacturing, Automation & Tooling Capability Group which enables the physical world of manufacturing to be evaluated in the digital world of design. The group bridges the gap between manufacturing data and conceptual design so that products can be developed and digitally validated before they reach the factory floor. The team uses CAD and CAM software to simulate manufacturing processes and evolve designs to improve production. The group also encompasses tooling, automation and metrology teams so that all the

---

r Asgard, European Artificial Intelligence Landscape, 2017
See https://asgard.vc/
steps needed to transform a concept into a product are integrated.

The Warwick Manufacturing Group is also an academic department at the University of Warwick and has developed a research theme in Intelligent Vehicles underpinned by a key facility: a drive-in, driver-in-the-loop multi-axis simulator. Their simulator has a world-leading capability to fully emulate the external environment that a vehicle would encounter on road, for repeatable testing and verification whilst their intelligent vehicles research brings together several capability areas such as Complex Electrical Systems, Communications. Clearly, UK government has recognised the importance of advanced data analytics and after the publication of Dame Wendy Hall’s review has now launched the Sector deal for Artificial Intelligence as well as the Industrial Strategy Grand Challenge on Artificial Intelligence and Data which seeks to embed AI across the UK and enable industries to use this technology to identify better ways of doing complex tasks.

7. Industrial Leadership

Given their access to real data, it is businesses like Google, Apple, Microsoft, Amazon and the former Cambridge Analytica who have been leading the way in Artificial Intelligence at present. This is due to their ability to use deep learning techniques that are relevant across the business world, but particularly in the retail sector and its desire to understand consumer data better.

The majority of these big players are UK based companies and are featured in the latest Artificial Intelligence Sector Deal publication\(^5\). Other companies identified in this document include BT, DigitalGenis, Beyond Limits, Ironfly Technologies, Astroscale and Chrysalix.

The DataIQ\(^1\) top 100 list of the most influential in data driven businesses, does include leading industrial systems organisations include Dyson, Southern Water, Thames Water, Mars Petcare, Virgin Atlantic, Unilever, GlaxoSmithKline, Jaguar Land Rover and Shell.

Much of the list however, is made up of insurance companies and supermarkets as well as the financial sector.

We also know that through the Digital Engineering and Manufacturing Leadership Group, there is representation from key industries including Siemens, Airbus, Meggitt, GKN Aerospace, Jaguar Land Rover, Bentley, Gambica, and IBM.

In addition, through the AI Sector Deal we will now create an AI Council of leaders from both academia and Industry to oversee implementation of the deal, but also drive the AI agenda, work closely with and support industry and advise government. Clearly, leadership within UK Industry has been identified. In the Made Smarter Review there is a recommendation to create a Made Smarter UK Commission (MSUK) that again would be a national body made of industry and academia who would lead on the adoption and diffusion of IDTs in the UK. In addition there is a call to create Strategy & Support Implementation Groups (SSIGs) to help roll out the recommendations and again this would include industry alongside academia and government.

Pricewaterhouse Coopers (PwC)\(^1\) have highlighted just how they are supporting data analytics in the manufacturing sector and have provided four case studies which illustrate the diversity of the use of data analytics within a manufacturing company:

- Improving the effectiveness of supermarket promotions for food manufacturer
- Customer and product profitability insight
- Insights into post deal synergies
- Proof of concept data visualisation tool for parts supplier

Interestingly, it is the supermarkets who are supporting food manufacturers by enabling increased sales through insights into customer behaviour.

At the same time, Deloitte has produced a report on Big Data & Analytics in the Automotive Industry\(^2\) which also highlights the diverse nature of analytics for decision-making that the manufacturing sector is


\(^1\) See https://www.dataiq.co.uk/dataiq100

exploring.

- 50% of those polled stated that they didn’t clearly understand the difference between business intelligence, big data analytics, and predictive analytics. Coupled with the result that an equally small number have a clear idea of business benefits potentially available through the use of big data solutions, it is clear there is still much to do before big data experiences widespread adoption.

- 41% of those surveyed are currently at the experimental stage, beginning to research and understand big data architecture and the potential business value; a figure expected to fall to just 11% within three years.

Indeed adoption of data analytics clearly remains a challenge to be overcome with companies, especially SMEs perceiving challenges around data being unstructured - a lack of the right data. More than that though, the report did highlight that that was also due to a lack of leadership and acceptance internally in most organisations.

8. Research opportunities for Data Analytics and Decision making for future industrial systems

It is clear, however, that a large proportion of the research funding is being allocated through Centres for Doctoral Training on broader fields of study that include web science, data science, cloud computing and cyber security.

Further research is required to really bring together the broader industrial digital technologies with future industrial systems in order to tackle some of the challenges that digitised data advanced analytics can bring.

For example, research needs to be undertaken to ascertain how we solve high level data fusion and data interoperability and information standards challenges to create connected infrastructures and to ensure that we can respond in real time to enable industry to become data driven in terms of real time production decisions but also real term manufacturing as a service.

There is under-development in the area of sensor fusion for process control. Many processes consider sensors in isolation and monitor them without considering the impact of other sensors. This is a clear area where data analysis could improve the process as it would reduce waste, produce higher quality products and allow for production performance data to be collected for quality control.

Condition based monitoring in academia is a well-researched topic with a variety of methods for different components such as bearings, gearboxes, motors and shafts. However, much of this research occurs in tightly controlled, artificial environments, with little translation towards real world applications. Furthermore, condition based monitoring is usually undertaken at the component level and there is little research that focuses on the whole machine.

Control of machines like cutting tools and robots require fast servo loops therefore the data analytics must be fast probably within milliseconds. Continuous feedback loops are still in operation and the digital data analysis’s sit outside the loop. This will change as AI will be a feature of silicon chips in the future, these intelligent chips will be close the actuators with the ability of making decisions within nanoseconds. This will also impact on ease of set optimal performance.

It should also be noted that there could be further research required to enable adoption of data analytics and decision-making. Applied research activity may be more appropriate here as it is important to be able to use real data sets and tackle real industrial AI data analytics and AI challenges.

“Manufacturers need practical guidance. Most academic research is tangential to corporate needs. Academics push technological frontiers, from Artificial Intelligence to deep learning, without considering how they will be applied. Manufacturers want to know what types of data to sample, which sensors to use and where along the production line to install them. For example, to improve ceramic-material quality, which is challenging to attain, a manufacturer might want to monitor the performance of machinery as well as the structure of the product. Research is needed to determine the best configurations of sensors. Five gaps in smart
manufacturing innovation need to be filled”.\textsuperscript{v}

This kind of research could include the development of data visualisation including Augmented Reality and Virtual Reality, the interaction of human or social data and machine data, or the issues of trust in sharing data when there may be a perceived threat from future smart systems.

\textsuperscript{v} Nature, \textbf{544}, pp 23–25 (06 April 2017) doi:10.1038/544023a