THE 2018 WORLD MANUFACTURING FORUM REPORT

Recommendations for the Future of Manufacturing

World Manufacturing Forum
WMF

Please, use the following format for references and citations: *2018 World Manufacturing Forum Report, Recommendations for The Future of Manufacturing*

More information on the World Manufacturing Forum can be found at www.worldmanufacturingforum.org

ISBN: 978-88-943861-1-0

THE 2018 WORLD MANUFACTURING FORUM REPORT

Recommendations for the Future of Manufacturing

World Manufacturing Forum
WMF

Foreword

Dear Readers,

Throughout history, manufacturing has held an important role in society, driving innovation and human progress forward. As a vital part of the world economy, manufacturing is a profoundly important topic for all global citizens. With the *2018 World Manufacturing Forum Report - Recommendations for the Future of Manufacturing*, the World Manufacturing Forum (WMF) aims to reinforce and support its mission by enhancing and spreading industrial culture worldwide.

This white paper will examine relevant topics for current and future manufacturing stakeholders and provide recommendations for future action. To better understand the roles of manufacturing and future outlook, this white paper will analyse the current state of manufacturing in numbers, societal megatrends and manufacturing challenges to discover what actions are needed in the journey of achieving future-oriented development.

Therefore, the main purpose of this report is the identification of ten key recommendations by the WMF to be adopted, both in the short- and long-term time frame, by policymakers, industry in general and by other relevant stakeholders including individuals, academic institutions and associations.

We believe the findings and recommendations in the 2018 WMF Report are useful and accessible for a wide range of stakeholders in order to collaborate within the manufacturing industry and to support a prosperous future for all. The World Manufacturing Forum therefore encourages the implementation of this report's recommendations to accelerate the transformation of the manufacturing industry toward global resilience, thus enhancing societal well-being.

We hope this document will both advance internal corporate discussions of the topics covered and contribute to a larger public debate, to be initiated at the 2018 World Manufacturing Forum - Annual Meeting held on the twenty-seventh and twenty-eighth of September in Cernobbio, Italy. Following the release of this report, our aim is to actively work with members of the World Manufacturing Forum and with manufacturing stakeholders to see how these recommendations fit into business practices and other initiatives within the public and private sector. In the coming years, the World Manufacturing Forum will produce further research and analysis to provide actionable insights for leaders to respond to changes around the globe. We aim to encourage engagement in dialogues with key stakeholders involved in shaping the future as well as work closely with public and private sector actors to introduce new initiatives. In subsequent publications, report methodology will be extended to include additional perspectives with close collaboration between government and industry stakeholders to ensure a successful future of the manufacturing industry – and with it a positive outlook for the world economy.

We encourage and invite other initiatives and stakeholders to join us in exploring the potential to inspire responsive and responsible actions for industry leaders. The time to act is now.

-The 2018 WMF Editorial Board

Index

Executive Summary

The *2018 World Manufacturing Forum Report: Recommendations for the Future of Manufacturing* aims to outlining the significant megatrends and challenges affecting the global quality of life, create a new vision for the manufacturing of the future considering individual attitude, and, finally, propose the key recommendations to promote the global resilience.

Manufacturing follows continuous progress driven by new emerging technological innovations to reinforce sustainable and resilient growth. This progress of the manufacturing industry should be enriched through continuous investment in R&D, reaching more end-users, creation of new jobs, alignment with the Circular Economy paradigm, the *Fourth Industrial Revolution* and skills reallocation.

Global issues – such as an ageing population, creating inclusiveness in the workplace, worsening scarcity of natural resources, steady migration and growing industrialised areas, digitising interconnection, strengthening cyber threats, and progressive global warming - trigger new policy proposals and innovation developments that are reshaping past thinking of industrial evolution.

The weaknesses of industrial systems decelerate progressive and sustainable development. The 2018 WMF Report will examine nine significant manufacturing challenges: competences and skills gap for advanced manufacturing, global-local agile supply chain networks, integration of IT, OT and ET, scarcity of natural resources and reduction of energy consumption, mass personalisation, hybrid and smart materials, data-driven manufacturing, data security and data authority, and SMEs' digital divide. These will greatly impact the manufacturing industry into the future. It should be noted that these manufacturing challenges are highly interdependent and must be considered in relation to one another.

The 2018 WMF Report will present the Future-Oriented Manufacturing - a new industrial vision built by multi-directional focus to reinforce sustainable growth and enhance global societal prosperity. In this respect, six disruptive trends for the future of manufacturing, likely to play out simultaneously and not alternatively - Inclusive Manufacturing, Cognitive manufacturing, Global Risks-Resilient Manufacturing, Hyper-Personalised Manufacturing, Circular Manufacturing, and Rapidly Responsive Manufacturing - must be considered as a source of great opportunity to deliver solutions of excellence.

Further, the 2018 WMF Report proposes the key recommendations to be adopted by manufacturing stakeholders globally. By envisaging and supporting the implementation of these ten short- and long-term recommendations, developed with the advice of high-level industrial, governmental and academic experts and international best practices to guarantee their global relevance, the World Manufacturing Forum shapes a framework for the evolution of the manufacturing role toward societal well-being.

The *2018 World Manufacturing Forum Report: Recommendations for the Future of Manufacturing* therefore aims to reinforce the importance of manufacturing in national and international agendas. The future-oriented scenarios and vision introduced in this report provide a starting point for considering a range of options possible for future development of the manufacturing sector globally. The key recommendations are designed to help governments and industries to identify and prioritise key actions for industrial development that are likely to promote a future that ensures societal prosperity and sustainable development.

Project Methodology

The *2018 World Manufacturing Forum Report - Recommendations for the Future of Manufacturing* aims to showcase how manufacturers can enhance societal prosperity and sustainable development through best practices and international collaboration. Given the objective of the World Manufacturing Forum to enhance and spread industrial culture worldwide, this report will explore pertinent topics relevant to the future structure of the manufacturing paradigm.[1]

Topics were selected for this white paper based on the 2018 WMF Annual Meeting objectives and literature reviews conducted from relevant manufacturing and governmental reports within the past five years. Feedback was also given from industry, academia, and government stakeholders. After the report structure and chapters were finalised, information used to develop the report was collected along with contributions from a panel of international experts.

Expert interviews were conducted among leading officials from manufacturing companies, world-renowned universities, and both governmental and non-governmental organisations. Experts were selected based on high-level knowledge, as demonstrated through published research and papers along with being an internationally recognised leader in the manufacturing community.

Experts were asked to evaluate the validity of selected topics with regard to societal megatrends, manufacturing challenges, and future-oriented manufacturing. Experts were also asked to give examples of best practices within the manufacturing community and provide short- and long-term recommendations to achieve future goals for social prosperity. Over thirty interviews were conducted and all data was collected and analysed for correlations and common themes. These expert interviews allowed for greater input for key rec ommendations. Additionally, some experts completed case studies in their area of expertise in order to showcase best practices and highlight information at the regional, national, international, and industry levels.

Through the generous contributions of expert researchers, academics, and manufacturing leaders, the Editorial Board of the 2018 WMF Report aims to provide a holistic perspective that offers accurate, non-partisan information that will help the next generation of manufacturing to flourish, creating a better world for all.

Introduction

Manufacturing is critical in creating resilient economies that can adapt to face new manufacturing and societal challenges. Resilient economies are created throughout the world due to manufacturing's role as path for development and a driver of economic growth. A strong industrial sector helps nations to develop other important sectors of their economy and create positive economic growth.

Similarly, as nations benefit from resilient economies, political well-being is also improved. Manufacturing often serves as a *Peace Keeper* among nations. As the world becomes more industrialised and value chains are more interconnected, manufacturing is able to unite nations and foster positive working relationships in the realm of international trade. With production processes and value spread throughout the world, peaceful relations and global cooperation are necessary to allow for business and progress. The majority of international trade is conducted through goods, placing manufacturing at the core of the global trade paradigm. Manufacturing helps to drive interregional and global economic connectedness through trade. These relations help to build a strong, active and competitive global economy.

Furthermore, the quality of life for citizens is considerably higher in nations with a strong industrial sector. A robust manufacturing sector helps to create stable jobs and value within a society, leading to more skilled workers, higher wages, and an overall increase in standards of living. These relations help to promote internal peace and well-being.

In addition to creating stable jobs for skilled workers, manufacturing also plays a key role in the service economy. Services are dependent upon manufactured goods for job creation. As a result, manufacturing helps to sustain service sector jobs which are critical in helping grow all aspects of modern economies.

Not only does manufacturing drive services forward, but it also helps to increase technological innovation. Research and Development (R&D) is a critical part of manufacturing processes and leads to great discoveries, improvements, and significant technological progress. These improvements often help to make manufacturing more efficient and safer, creating best practices while also offering better and lower-priced goods to consumers. Technological innovation helps to create an upward cyclical trend leading to more advanced and responsive manufacturing.

The manufacturing industry also serves as an innovator for sustainability. The circular economy helps to promote de-materialisation in the industrial sector with reuse and zero waste of materials. Information technology coupled with advanced manufacturing practices have helped to transition manufacturing practices to the circular economy.

Overall, manufacturing can be seen as an architect for social prosperity and creation. While it plays a vital role in the global community, many future challenges for manufacturing exist. The continuous progress of industry leads humans to a higher development level, demanding greater progress, innovation, and standards of living. Manufacturing holds a key role in addressing emerging societal and industrial trends through technological development and best practices. Manufacturing stakeholders have an important role in helping to increase social prosperity.


8143
49868
608

Section 1

Manufacturing in Numbers

Innovation within manufacturing was spurred by waves of transformations in major sectors supported by R&D investments from manufacturing companies and public funds. This transformation produced high-value manufactured goods in regions across the globe while investing in technological innovation.

Recently, major national and international organisations along with consultancy companies have been measuring the effects of the application of the *Fourth Industrial Revolution* technologies to selected major manufacturing sectors worldwide. They have presented their findings in various reports in the form of numbers assessing the evolution of selected key performance indicators.

In order to make recommendations in this report and beyond, understanding the current state of manufacturing through a numerical research perspective helps to provide background and insight into the future of manufacturing. Though industry is presented with data in many different areas, it is important to understand the most pertinent and pressing issues which will be at the forefront of the manufacturing paradigm.

This established knowledge provides a foundation on which to base future industry research, predict and anticipate future trends.

In this section, we will examine key messages extracted from the study of numbers presented in the most recent and relevant published reports which assess the effects of the *Fourth Industrial Revolution.* All of these reports present clear numerical research that will help to better understand the future trajectory of manufacturing in five vital areas.

Manufacturing and Industrial Technologies are Major Drivers of Societal Wealth Around the World

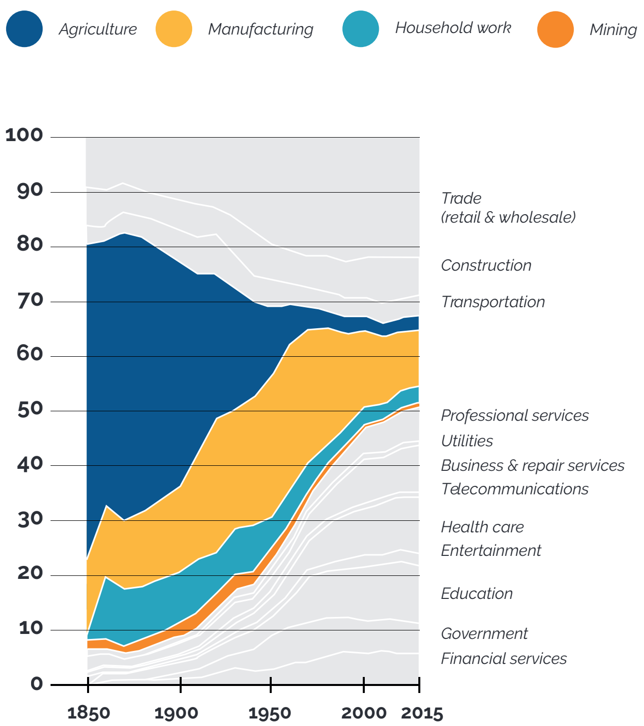
Without doubt, manufacturing has become a major driver of the global economy both in terms of jobs as well as overall wealth.

Since the *First Industrial Revolution*, jobs within major economic sectors have changed drastically. Among these changes, manufacturing absorbed a major part of the jobs lost in agriculture. At the same time, it was a driver of jobs created in other sectors such as trade, professional services, education and financial services. This is due to that fact that daily activities within these sectors are dependent on manufactured products.

This is illustrated in Figure 1, which shows the changes in share of total employment in the United States from 1850 to

2015.[2] A very similar trend can be considered for many other economies.

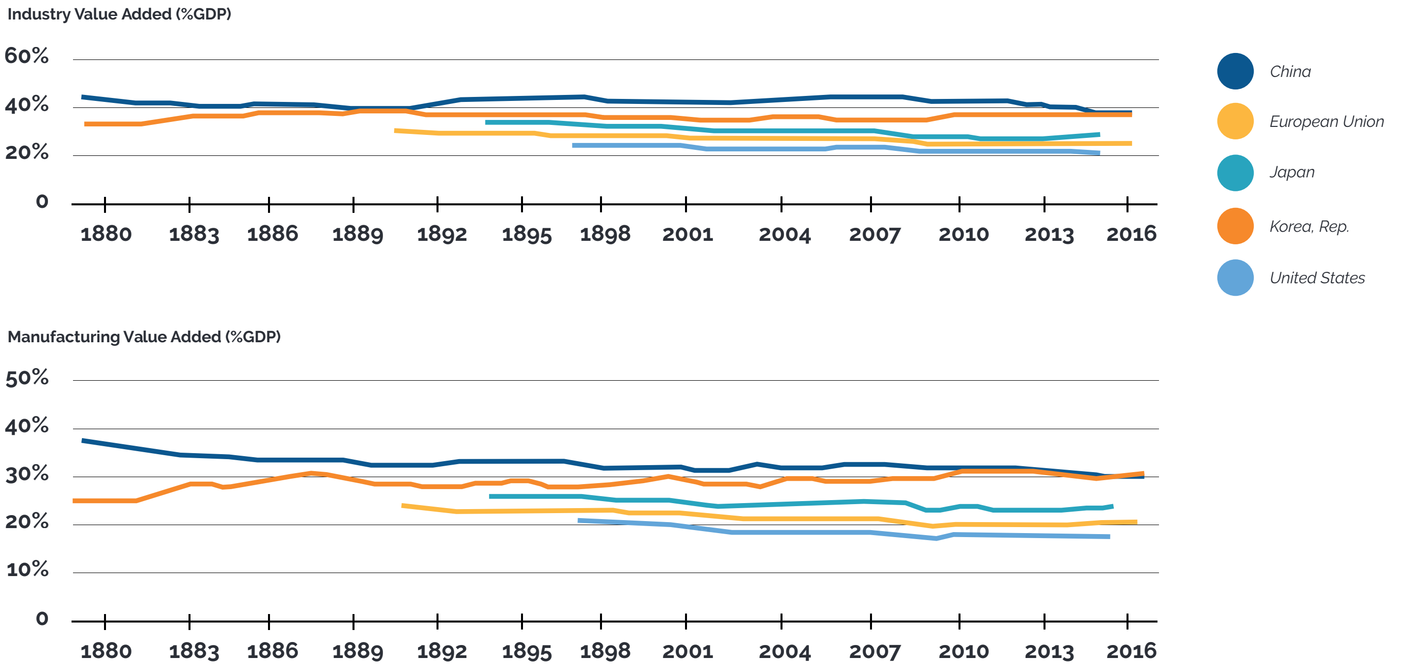
Figure 1 - Share of Total Employment by Sector in the United States, 1850-2015
(Source: McKinsey Global Institute)



History shows that while technology has created large employment and sector shifts, it also creates new jobs Moreover, recent data from the World Bank proves that industry can contribute between 20% to over 40% of the Gross Domestic Product (GDP) of major industrial regions of the world, with manufacturing as the main contributor to industrial GDP (See Figure 2).[3]

Further, it can be observed in Figure 2 that since 2000 Europe, in particular, has experienced a significant de-industrialisation. As is stated in the recent document, *Re-Finding Industry: Report from the High-Level Strategy Group on Industrial Technologies*, the contribution of manufacturing to European GDP decreased from 18.5% in 2000 to 15% in 2012 and 3.8 million jobs were lost between 2008 and 2012 in the industrial sector.[4] However, this does not indicate that industry is going in the same direction as agriculture did about a century ago but rather with a slow yet continuous reduction in its overall role in the economy. Throughout the world, industry is central to the economy. It contributes to prosperity through business in global and local value chains, and provides many jobs. In Europe, industry provides jobs to 36 million people, which accounts for one out of every five jobs in the region.[5]

Figure 2 - Share of industry in GDP in selected economies
(industry and manufacturing value added)
(Source: World Bank)



Moreover, the manufacturing sector is greatly important because of its major role in driving productivity and innovation. An hour of work in manufacturing generates nearly € 32 EUR of added value. With a share of approximately 16% of total value added, manufacturing is responsible for 64% of private-sector R&D expenditure and for 49% of innovation expenditure.[6]

Finally, some of the negative trends are reverting. For example, recent years have seen a reversal in the decline of EU manufacturing. Impressive growth rates include:[7]

- **Industry:** share in total value added increased by 6% since 2009;
- **Employment:** over 1.5 million net new jobs in industry since 2013;
- **Labour Productivity:** 2.7% average growth since 2009, higher than both the United States and Korea (0.7% and 2.3% respectively).

Manufacturing is Spreading Wealth Worldwide Through Global Supply Chains

The performance of any industrial ecosystem and consequently societal wealth depends on the performance of many end-use industries through their respective supply chains.

Major end-use sectors that are representative of their contribution to societal wealth are characterised by their abundance of heavy use of manufacturing technology products. The automotive, aviation and semiconductor sectors are representative of this trend. According to the *2016 Top Markets Report on Manufacturing Technology*, the value of the automobile manufacturing industry combined with suppliers of automobile parts and components is estimated between $1.2 trillion to $2 trillion USD.[8] In the civil aviation sector, the revenue of aircraft manufacturing together with suppliers of aircraft parts, subassemblies and components accounted for over $285 billion USD.[9] The combined number of orders received by the two major civil aircraft manufacturers, Airbus and Boeing, was 10,639 at the end of 2013. It is predicted that the demand for civil aircrafts will continue well into the future. The semiconductor industry has also been developed intensively during the last years and is one of the major pillars of the *Fourth Industrial Revolution* and accounted for $335.2 billion USD in 2015. The vast monetary value of these end-use sectors is indicative of the contribution to global wealth throughout many industrialised nations.

The production of automobiles, aircrafts and a wide range of products using semiconductor components require wide networks of multi-tiered suppliers. This includes consumer goods such as smartphones, TVs, laptops and all kinds of automation equipment and devices. This production also requires the use of various types of equipment such as machine tools, dies, jigs and moulds whose production is directly affected by industrial automation methods and tools.

Consequently, developments and advances in industrial automation are directly linked to and affect the performance of many categories of industries, particularly those that rely heavily on repeatability of processes with high-volume of output and high-quality requirements. Typical examples of such end-use industries are those presented above as well as high-demand, prolific consumer goods including food and beverage, furniture, clothes and shoes, metals and materials, oil and gas, packaging, pharmaceuticals and more.

In the case of the automotive industry, a single automobile car can have as many as 15,000 components and parts. In 2013, 86.9 million motor vehicles were produced throughout the industrial world.[10] The automotive industry is a high-volume manufacturing industry which focuses on mass-production, and relies on multi-tier supply networks to provide components, subcomponents and parts for the vehicles to be produced. Engines, breaks, bearings, seatbelts, wheels, tyres, entertainment and infotainment systems, the car body and most parts of a vehicle are currently produced in highly automated factories using advanced intelligent machinery and robotics.[11]

The assembly of motor vehicles is highly automated as well. According to reports of the International Federation of Robotics (IFR), the automotive sector is the largest end-user of industrial robots, with around 98,900 installed robots in 2014.[12]

Another major end-user of industrial automation equipment and critical to all consumers is the food industry. Food production is estimated at over $750 billion USD in the US alone.[13]

In a recent study, McKinsey estimated the value of the global food and agribusiness industry at $5 trillion USD.[14]

Globally, as it is reported in the *Roadmap for Pushing Man-*

ufacturing Forward, the manufacture of goods is constantly progressing at a strong rate.[15] Between 2000 and 2014, the World Trade Organisation reports that the global trade of manufactured goods has almost tripled, from $4.8 trillion USD to $12.2 trillion USD.[16]

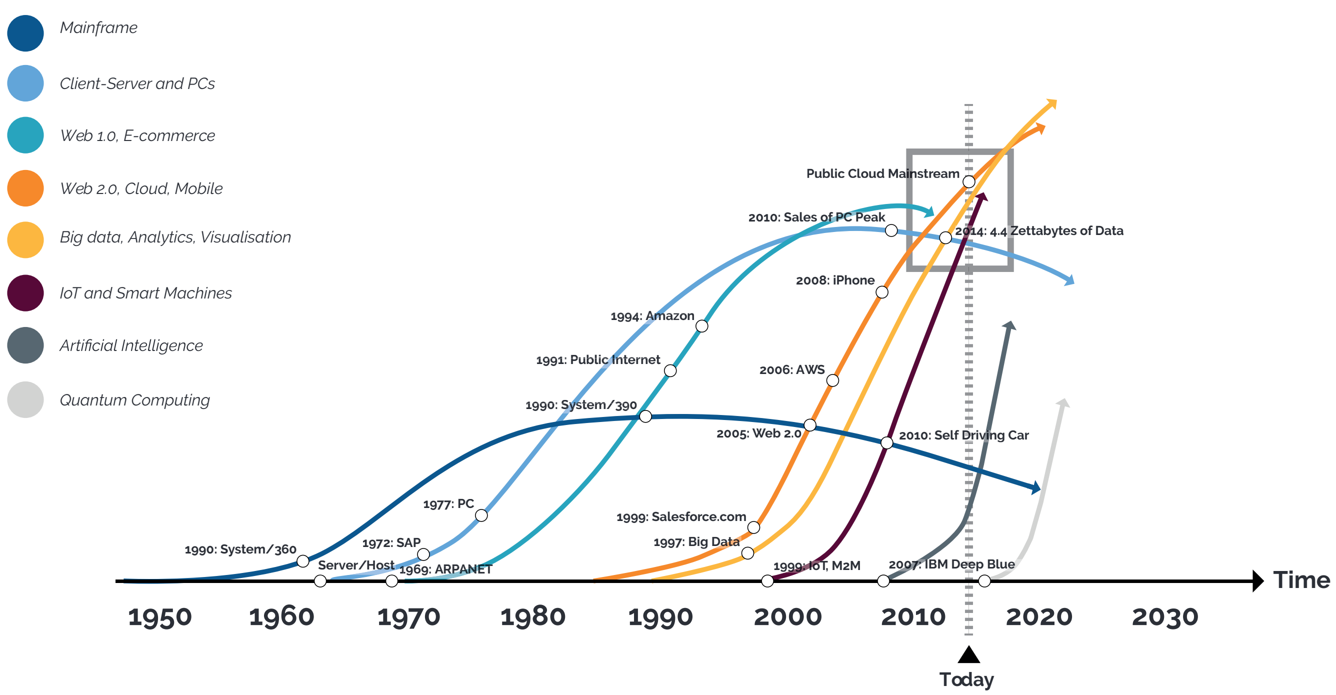
These end-use sectors which are heavily dependent on industrial automation are critical to adding to global wealth throughout the supply chain and in their end-use. Vast increasing numbers signal the current and future value of these industries which in turn will provide better, more affordable goods for consumers while also creating jobs and adding to the world economy.

Manufacturing is Transformed by Digital and Cognitive Technologies and is Becoming Connected and Data Driven

Industry 4.0 and the Industrial Internet of Things (IIoT) are revolutionising the way the world works. Both of these conceptual and technological innovations create via connected technologies and various IT platforms not only highly efficient relationships between products, machines and services but also between customers, workers, managers, suppliers and partners. They constitute, in short, the main bridge between the physical and digital enterprise applications realising the so called *Fourth Industrial Revolution*.

The combinatorial capability of all these technologies (See Figure 3) is revamping practically every business practice, whether in resource allocation, process and operation sequencing and routing, materials handling, workers' involvement, customer relationship or environmental management.[17] The combinatorial effect refers to the cumulative capability of the main new technologies combined together to produce impact. For example, how one technology influences the other throughout time, the former allowing the latter to create greater impact by combining the results and the effects of the consequently invented technologies. Costs and prices of many technologies critical to Industry 4.0 including cloud computing, processing power, storage space, data analytics, connectivity, and components such as sensors, have dropped over the last two decades, making these technologies affordable to many manufacturing sectors and companies. Prices have also dropped by up to 50 times compared to only a few years ago (See Figure 4).[18] The increased accessibility of Industry 4.0 technologies can be attributed to two reasons. First, the use of advanced manufacturing practices in the semiconductor industries allowed for higher production volumes and lower prices. Second, demand and need for these technologies became widespread throughout the globe.

Figure 3 - The Combinatorial Effect of Technology
(Source: Accenture)

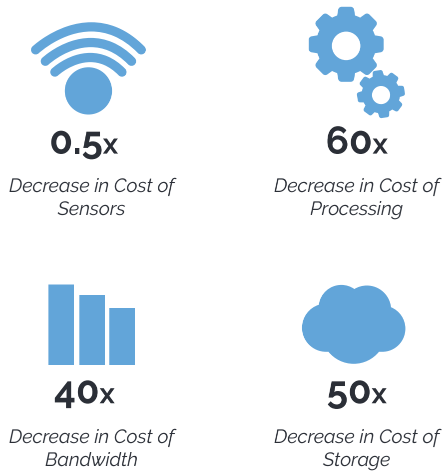


According to Accenture, the *servitisation* of products will gain interest and application in all industrial sectors over the coming years.[19] Once some companies prove they can deliver outcomes profitably, this will force their competitors to do the same. More and more producers of various categories of goods will be looking at ways to develop profitable services and attach them to their products. These will then become *Product Service Systems* which companies can propose to their customers. Further, this will lead to situations where services will produce more value for the company proposing them than the associated physical product itself (see Figure 5).[20]

Not only does this help to drive innovation and best practices within industry but society will ultimately benefit from better and more technologically advanced goods at a more competitive rate, helping to raise global living standards.[21]

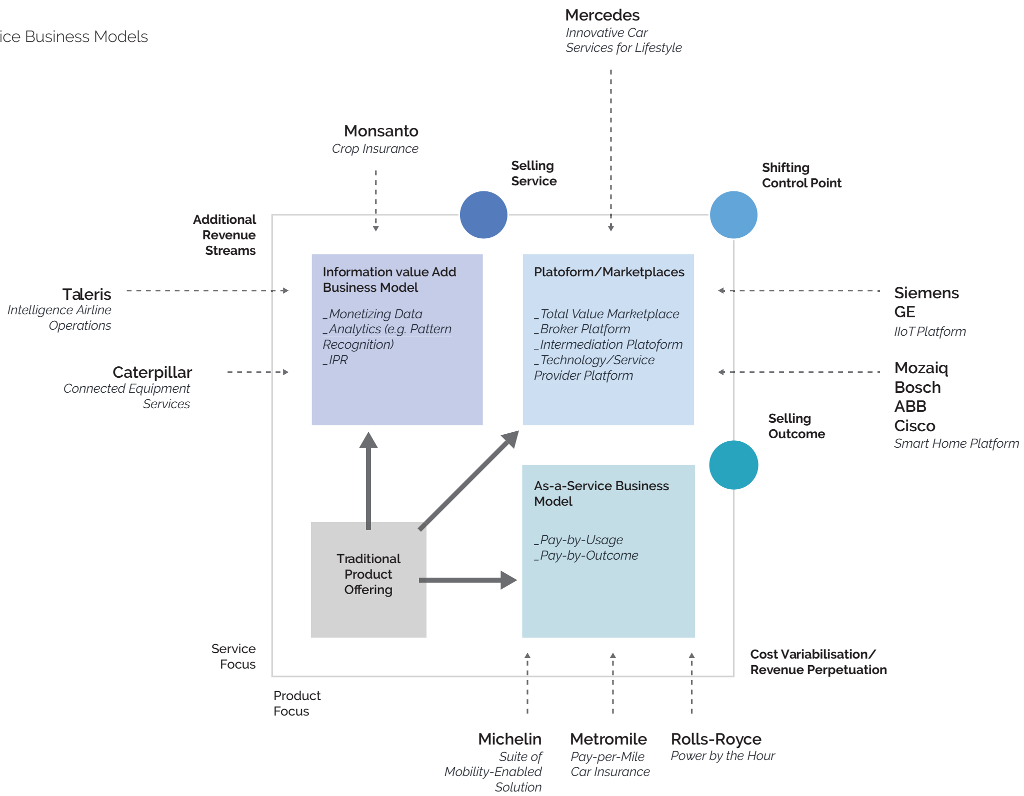
These digital technologies and innovations are also driving impressive and massive changes and improvements in the supply chain. However, digital disruption and established globalisation are also creating higher expectations among customers which in turn places stress on supply chains.

Figure 4 - A Decade of Eroding Cost Fuels the Rise of the Internet of Things
(Source: Accenture)



The *2018 MHI Annual Industry Report* includes key findings (See Figures 6, 7 and 8) regarding the top supply chain innovations, respective adoptions rates and the barriers to adoption, based on survey responses from more than 1,100 manufacturing and supply chain industry leaders across a wide range of industrial sectors.[22]

Figure 5 - Products as a Service Business Models
(Source: Accenture)



Industry Renaissance: Knowledge and Know-How Mastery, not Production Dominance, Determine Market Leadership

Florence Verzelen
EVP Industry Solutions, Marketing, Global Affairs and Communications, Dassault Systèmes

A global Industry Renaissance is gaining momentum, a transformation in which superior mastery of knowledge and know-how – not production efficiency alone – determines market dominance.

Today's leaders – think of Google, Amazon, Facebook and Alibaba – combine products and services to deliver customer-delighting experiences, often without any manufacturing capability. Superior mastery of knowledge (what data means and what to do with it) and know-how (how to do what needs to be done) is their secret weapon for beating the competition.

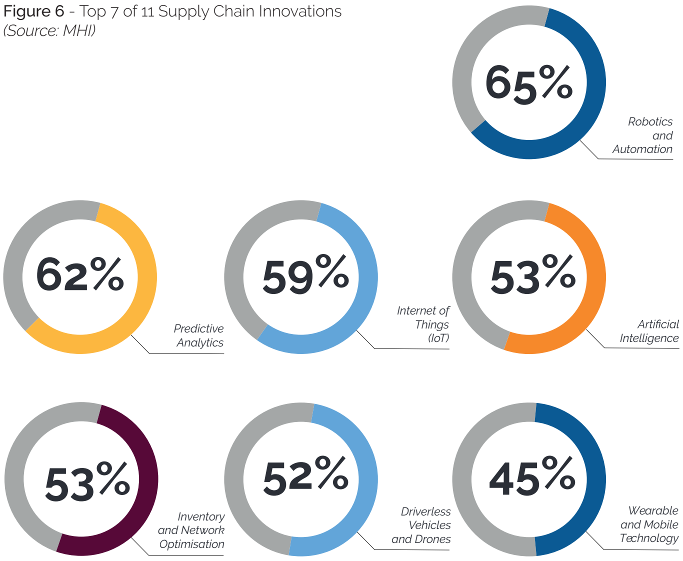
For Manufacturing, Industry Renaissance represents a much larger opportunity than digitalising the factory floor. Whether you are part of an experience-creating organisation or an external manufacturing partner, you have the knowledge and know-how to optimise manufacturability, minimise costs, accelerate production and improve sustainability. You can't add this value as an afterthought; you must leverage that expertise from day one. But how?

Manufacturing leaders are seizing the opportunity of Industry Renaissance with a combination of two critical technologies: virtual worlds and digital experience platforms.

If your company (or your customer) designs and engineers in 3D, you already know the power of virtual worlds. These sophisticated, science-based simulations of real-world objects and assemblies – even entire cities – are the first major advance in knowledge and know-how mastery since Gutenberg invented the technology to mass-produce books. Today, virtual worlds serve not only as library, but also as classroom and laboratory; facilitate understanding by showing – not telling – what knowledge and know-how can achieve; and help leaders identify new opportunities to invent or improve experiences by generating insights from real-world IoT data. Made-for-cloud digital experience platforms have been the missing link in harnessing the full potential of digital worlds – a gap that has now been eliminated. A digital experience platform leverages all of an organisation relevant knowledge and know-how – including its manufacturing knowledge and know-how – in the context of virtual worlds, providing each company with new ways of collaborating both internally and with its supply network. Digital experience platforms also capture and reapply the knowledge and know-how developed through virtual worlds to accelerate innovation, skills development and production and delivery. Accessed via the cloud, a made-for-cloud digital experience platform allows even the smallest organisation to transform an industry – or create an entirely new one.

Industry Renaissance is transformative because it gives every inventor, startup and multinational company equal opportunity to reshape and invent markets. It gives every worker instant access to the knowledge and know-how to succeed. And it gives Manufacturing the means to assume its full and rightful place as a master of knowledge and know-how at every stage of a project, from ideation to delivery.

Figure 6 - Top 7 of 11 Supply Chain Innovations
(Source: MHI)



The supply chain executives who participated in the survey believe many of these supply chain innovations have the potential and the dynamics to disrupt the status quo and create a sustained competitive advantage for companies that embrace them. Potential disruption statistics of these innovations have been consistently increasing for at least three years (See Figure 9).[23]

These numbers are indicative of the changing digitalisation in the manufacturing paradigm which will ultimately spur innovation forward for the benefit of societal well-being.

Manufacturing is Transformed by Digital and Cognitive Technologies and is Becoming Connected and Data Driven

Industry 4.0 technologies are becoming the most important elements of *Advanced Manufacturing*. They combine IIoT, connected intelligent devices and data analytics in tools that are used by manufacturers to monitor, collect, exchange, analyse and deliver valuable new insights about their products and processes. This is the foundation of what can be defined *as The Connected Manufacturing Imperative* and includes two other imperatives, *The Quality Imperative* and *The Plant Uptime Imperative*.

The Quality Imperative

The Cost of Poor Quality (COPQ) can cost manufacturers a staggering 5% to 40% of sales.[24] Further, suboptimal manufacturing quality imposes significant downstream costs to almost every aspect of an organisation including underutilisation of assets, added scrap and rework expenses, warranty costs and lost sales.

Therefore, product-oriented *Zero-Defect Manufacturing* is becoming an imperative in its turn.

Figure 7 - Adoption Rate of Innovative Technologies in Supply Chain, in-use today
(Source: MHI)

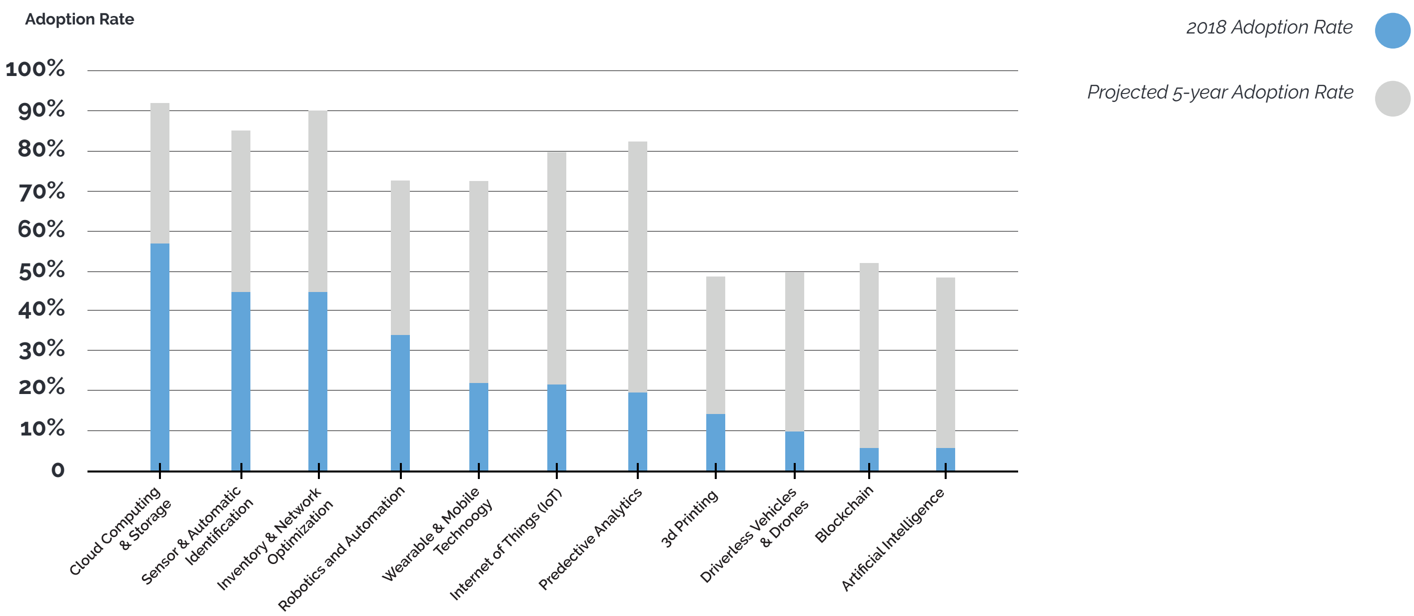
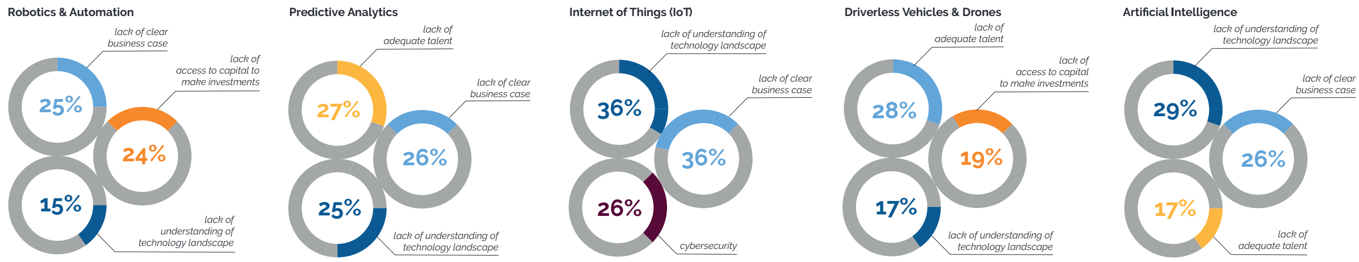


Figure 8 - Barriers to Adoption
(Source: MHI)



The Plant Uptime Imperative

When they occur, equipment and plant shutdowns cost manufacturers an inordinate amount of money. According to Deloitte, unplanned downtime costs manufacturers approximately $50 billion USD per year.[25] Deloitte has also found that poor maintenance strategies can reduce plant capacity by 5% to 20%.[26] Therefore, predictive maintenance for machine-oriented zero-defect manufacturing is also becoming an imperative. This signals a change in the manufacturing industry for higher quality goods and services which in turn adds more wealth and innovation to society.[27]

The aforementioned imperatives are becoming possible through the increased capacity and ability of industry to collect and analyse all kinds of manufacturing data in a cost-efficient manner. Accenture made a calculation using a representative car manufacturer with an assumed annual turnover of $50 billion USD.[28] The results are impressive and presented below in Figures 10 and 11.[29] The revenue and cost impacts are telling of the impact that data driven manufacturing has on the success of manufacturers.

Figure 9 - 2018 Survey Results: Potential to Disrupt or Create Competitive Advantage 4 Year Trends
(Source: MHI)

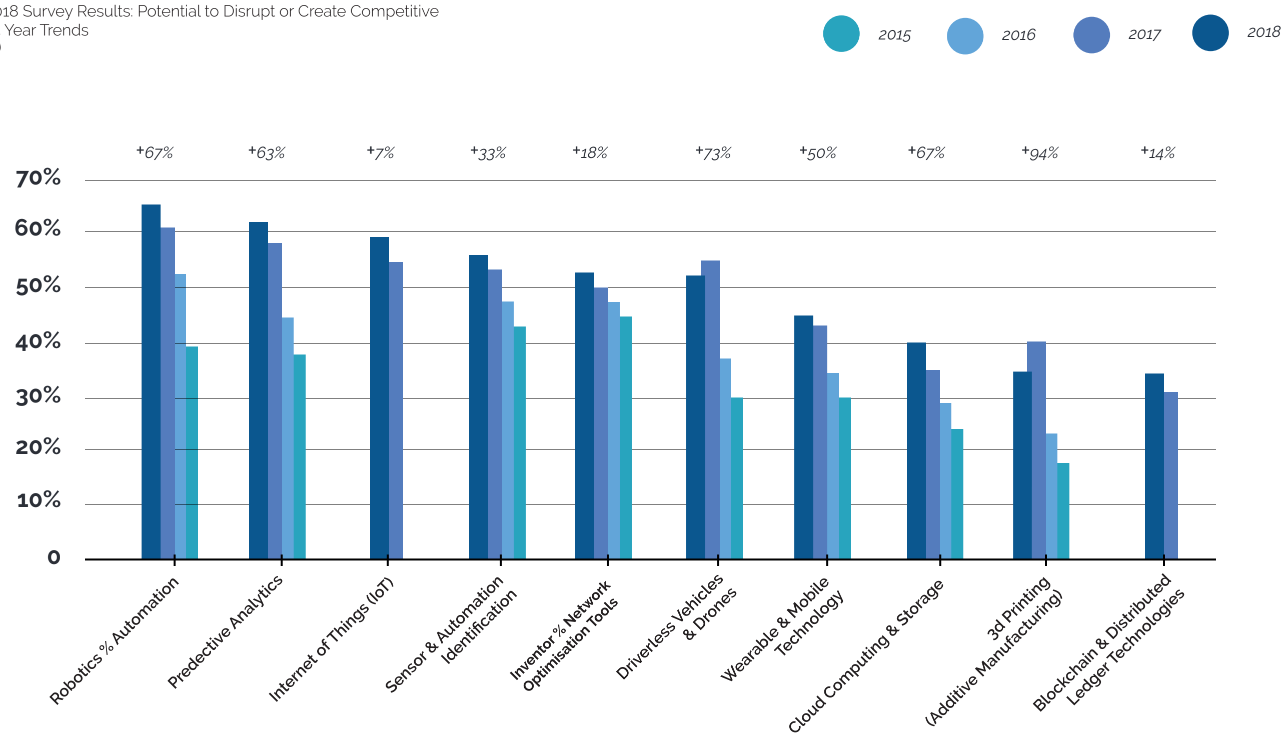


Figure 10 - Digitisation Levers and Value Potentials
(Source: Accenture)

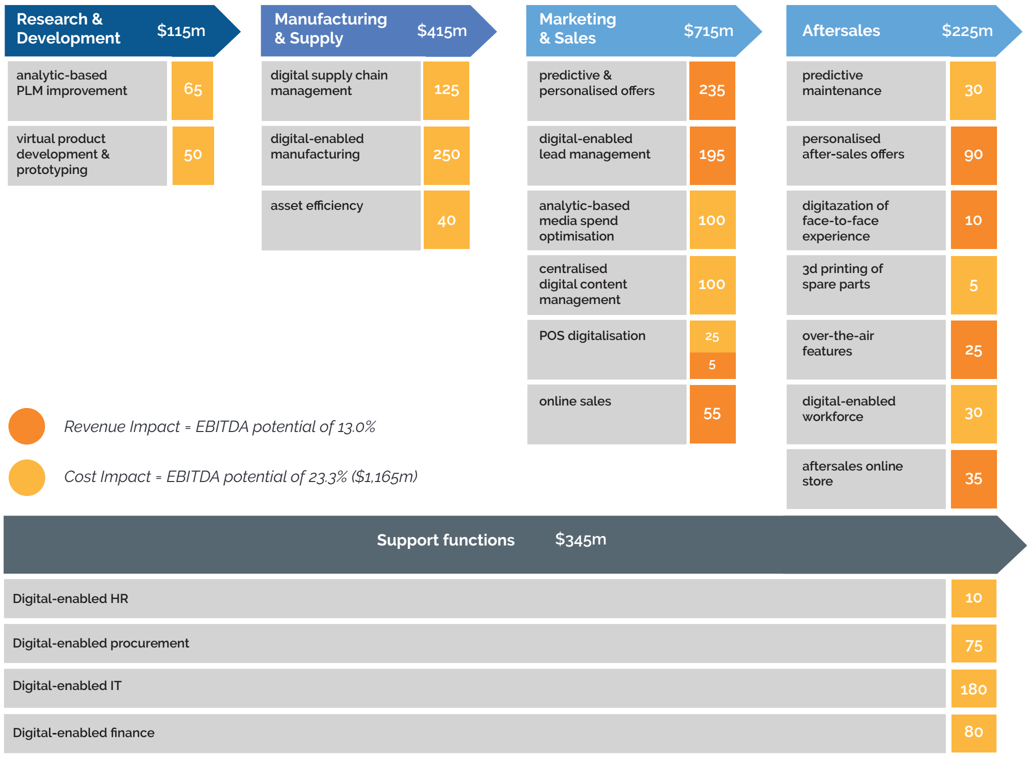


Figure 11 - Digitisation in Various Sectors-the Capabilities and Benefits
(Source: Accenture)

Sector	Connected Products/Digital Services	Business Outcomes
Connected Health	*_monitoring & treating illness* *_improving wellness*	*up to 20% reducing in desease burden* *$80-600 per year in wellness benefits for user*
Connected Home	*_core automation* *_energy management - Home* *_safety and security*	*17% time saved from relevant activities* *20% energy savings* *10% reducing in property damage incidents*
Connected Office	*_human productivity - activity monitoring* *_human productivity - augmented reality* *_energy monitoring - offices*	*5% productivity improvement* *10% productivity improvement* *20% savings*
Connected Factory	*_operations optimisation* *_predective maintenance* *_inventory optimisation* *_health & safety*	*5-12.5% cost reduction* *10-40% cost savings* *20-50% cost reduction* *10-25% savings*
Connected Operations	*_operations optimisation* *_improved equipment maintenance* *_health & safety management*	*5-10% increase in worksite productivity, 10-20% of consumables, 10-20% of personnel* *3-5% productivity gain, 5-10% of equipment costs, 5-10% of equipment maintenance* *10-20% decrease in health & safety costs*
Connected Transport	*_safety & security - personal transportation* *_passenger vehicles maintenance/replacement* *_aerospace equipment & maintenance*	*25% improvement* *10-40% reduction in maintenance & 3-5% longer vehicle life* *10-40% reduction in maintenance, 25% fewer delays, 3-5% longer aircraft life*
Connected City	*_air & water monitoring* *_adaptive traffic management* *_autonomous vehicles (fully and partially)* *_resource/infrastructure management*	*15% reduction* *10-15% less time in traffic, 10% reduction in congestion from smart parking* *40% accident reduction, 10-15% fuel/CO savings* *35% fewer electric outages, 50% reduction in water leaks, 10% reduction in theft*

Manufacturing Needs More Skilled Workers for New Types of Jobs

In its 2018 report *Technology and the Future of Work*, the International Monetary Fund recognises that adjustments and changes related to digitisation and Industry 4.0 technologies have been difficult.[30] The benefits from these transformations have been spread unevenly to involved stakeholders, particularly during the last decades of globalisation.[31] Technological change has eliminated some categories of jobs and transformed others. The manufacturing sector had a major contribution to the creation of new jobs. However, changes had dramatic consequences in many cases, as illustrated in shifts in the sectoral composition of employment from agriculture to manufacturing and during the last few decades from manufacturing to services. These shifts have occurred in many advanced economies, emerging markets and developing economies (See Figure 12).[32] As expected, shifts on such a scale had consequences and led to difficult adjustments for many categories of people all over the world.

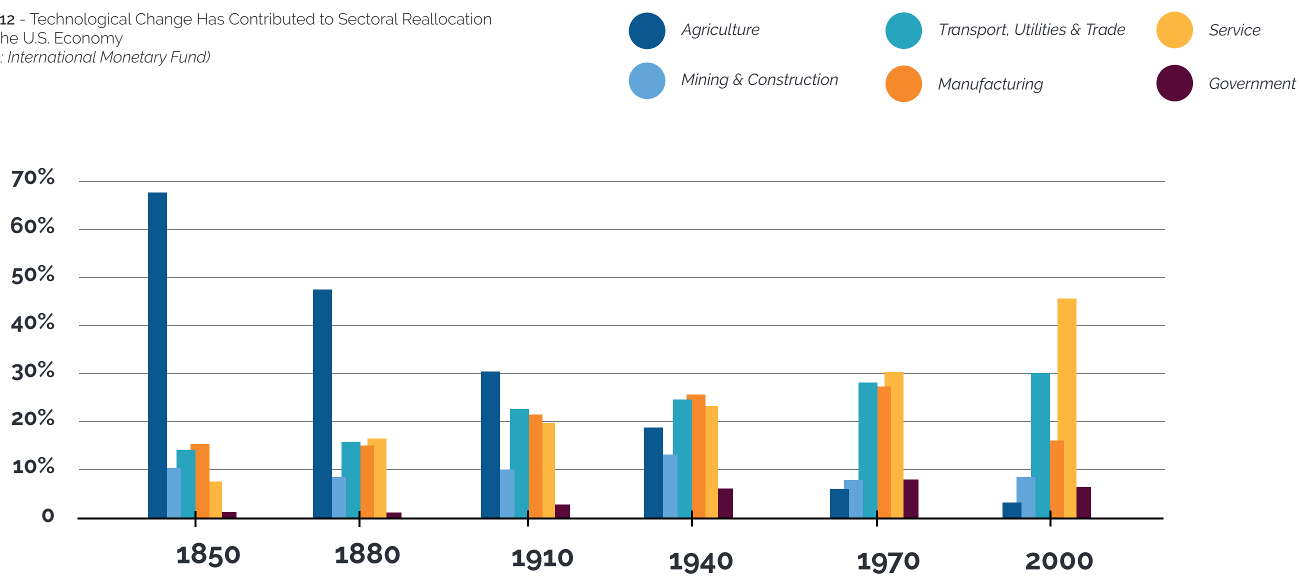
A key requirement in increasing manufacturing development is a sufficient supply of skilled workers. A German Industry 4.0 white paper predicts future factories as highly complex, dynamic and flexible systems that will need employees who are empowered to act as both decision-makers and controllers.[33] The European Commission speaks of the need for, "Six to eight new types of high skilled jobs to increase industrial commitment to stay in the EU."[34]

"Humans are still by far the most flexible production 'factor,'" as a Dutch white paper claims.[35] The factories of the future will not be labour-free, but will require employees with substantial vocational skills, some of which they do not presently have. This anticipated shortage of high-skilled technical labour poses a challenge to both industry and economy.

Manufacturers often experience problems and shortages in skills related to increasing requirements for specialisations necessary in advanced manufacturing operations and activities. For example, the fairly widespread growth in the number of engineering graduates over the last decade is not evenly distributed across emerging engineering subjects.[36,37] In the 2017 Global Digital IQ™ Survey, 63% of executives say that the lack of adequately skilled workers is an existing or emerging barrier to digital transformations of their companies.[38] As another example, the shortage of skilled and qualified personnel in assembling and shaping processes is estimated to be around 10,000 through 2020.[39]

A thorough analysis of the current situation has been carried out in Italy, identifying the top twenty advanced skill gaps as well as current countermeasures aimed at reducing such gaps (See Figure 13).[40] These results are stunning as only three areas indicate that more than 50% of respondents have countermeasures ready and in place to reduce skills gaps.

Figure 12 - Technological Change Has Contributed to Sectoral Reallocation within the U.S. Economy
(Source: International Monetary Fund)



2018 WMF Report ***Case Study***

Teaching Factory

Prof. George Chryssolouris
Laboratory for Manufacturing Systems & Automation (LMS)

Investment in education and training for skills development is essential to boost growth and competitiveness. World leading research efforts need to be translated into new products via efficient production methods. Talent-driven innovation is the major enabler of this process. Skill gaps and shortages hinder industrial innovation performance world-wide. Moreover, the employment pattern in manufacturing is changing towards more knowledge and skills intensive jobs. To effectively address the emerging challenges for manufacturing, education and skills delivery, the educational paradigm within manufacturing needs to be revised.

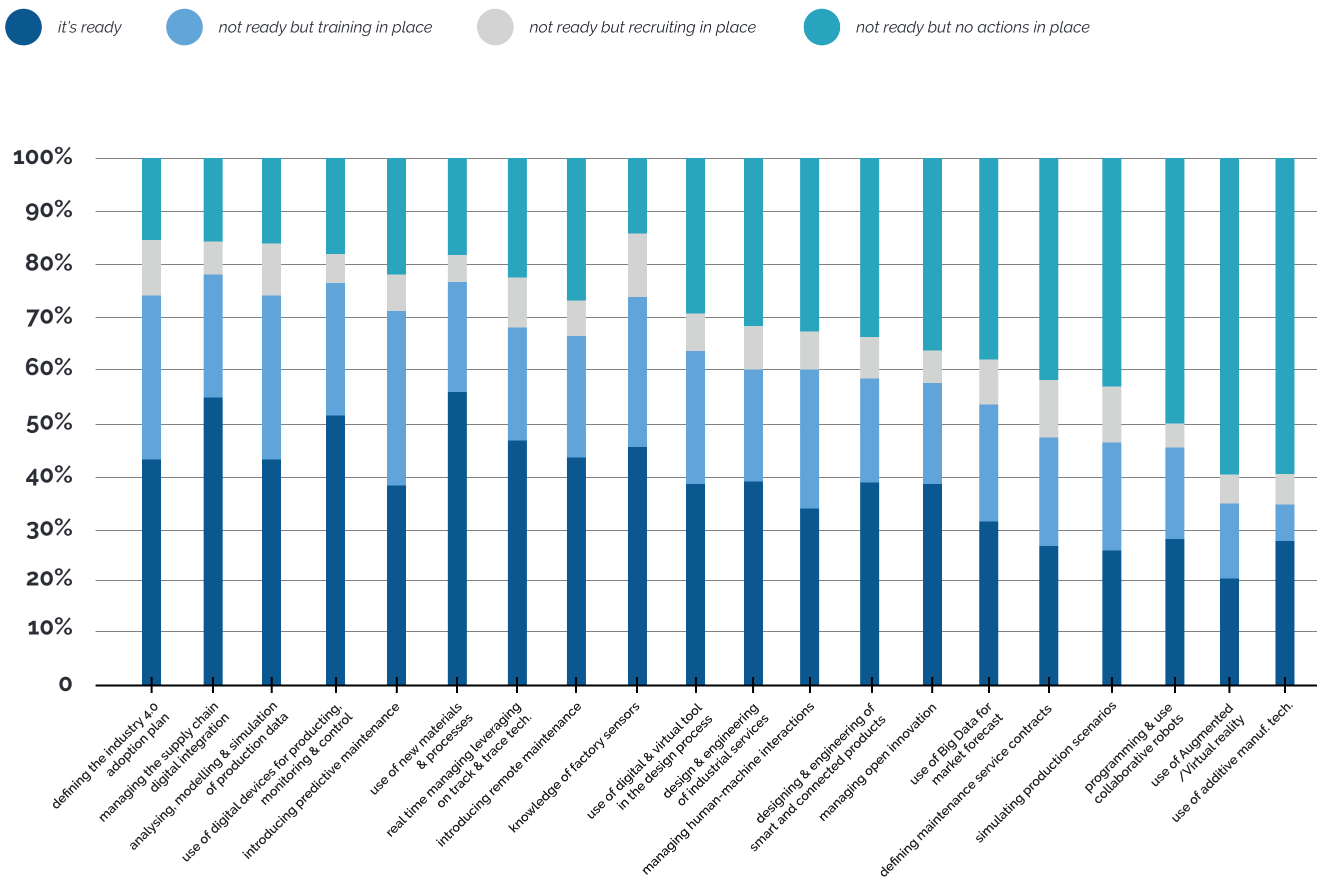
The Teaching Factory (TF) concept has its origins in the medical sciences discipline and specifically in teaching hospitals, namely medical schools operating in parallel with hospitals. TF has emerged as a promising strategy for integrating learning and working environments. It is a non-geographically anchored learning "space" interconnecting remotely located engineering and student teams that work together on real-life projects. TF is facilitated by advanced ICTs and high-grade industrial didactic equipment and operates as a bi-directional knowledge communication channel "bringing" the real factory to the classroom and the academic lab to the factory. Context and content modular configurations allow learning and training on multiple study contents, engaging different factory facilities, engineering activities, delivery mechanisms and academic practices.

The "factory-to-classroom" TF operation mode aims to transfer the real production environment to the classroom and to allow students to be trained by addressing appropriate real-life engineering problems. The actual production site is used to enhance teaching activities with the knowledge and experience that exist in the processes of every day industrial practice. The "lab-to-factory" TF operation mode aims to transfer knowledge from academia to industry. Industrial-grade or didactic equipment in the academic facilities are used as test-beds and demonstrators for new technological concepts that are to be validated and introduced to industrial practice.

The TF paradigm has been assessed based on real-life applications together with industrial organisations. Applications indicatively included the line balancing of a new production area and the planning of a material kitting area in a construction equipment factory, the validation of a new integration and control architecture for industrial robots in an automation company and designing a Multi-Technology Platform that combines a milling working center with a robotic arm equipped with a laser-head for a machine shop, etc.

The applications have demonstrated and verified the TF potential to bring together the manufacturing learning and working environments. Students can deepen their knowledge in certain topics and apply them in practice while addressing real-life problems and working in view of actual deadlines and industrial practice terms. Manufacturing practitioners have the chance to interact with a pool of students that have a problem-solving capacity, based on real talent and out-of-the-box thinking, and get ideas and solutions that may not have been considered during standard company engineering processes. In this way, TF may further add value through the introduction of a new form of "outsourcing", benefiting both the manufacturing company (in terms of resources) and the academia (in terms of access to real industrial needs).

Figure 13 - Countermeasures to Reduce the Top 20 Advances Skills Gaps
(Source: Observatory Industry 4.0 of Politecnico di Milano)



The Need for Industrial Learning Programmes

Promoting excellence in manufacturing is a strategic goal in the years to come for both industry and society. Manufacturing education is expected to be a major driver in achieving this goal particularly with the aforementioned skills gap.

In the current context, as shown by the previous messages and with regard to expected demographic changes such as the ageing of the population, there is a great need for programmes to educate and train various categories of people. This will allow them to develop skills and competencies to serve the emerging needs of the manufacturing industry while also remaining relevant and useful in their careers.

This requires a process of identifying and implementing professional competencies triggered by new scientific know-how and technological changes and then enabling these competencies in an industrial context to address new professional needs. For example, this may include what workers should know in order to contribute to new objectives such as business conversion, enlargement and modernisation. This process can be defined as *Industrial Learning*.

Industrial Learning will face major challenges as identified in recent studies.[41,42] Engineers and workers will need new lifelong learning schemes to assist them in keeping up with the pace of technological change which requires a continuous update of learning content, learning processes and delivery schemes of manufacturing education. Continuous training and lifelong learning are crucial for manufacturing companies to stay competitive in a global market.

The key challenges, identified by the ActionPlanT project funded by the European Commission, facing *Industrial Learning* are:[43]

- **Promotion** of synergy between the different *Industrial Learning* stakeholders especially research, industry and training bodies;

- **Comprehension** of the new professional needs in terms of ICT of the manufacturing industry for training. There is a need for a mechanism capable to be continuously updating the professional needs of the company;
- **Integration** of research and innovation with education and training activities;
- **Definition** of ICT for manufacturing skills required by the manufacturing labour force to face new professional needs;
- **Adaptation** of educational content and its delivery mechanisms to the new requirements of ICT based manufacturing;
- **Recognition, formalisation and strengthening** of learning taking place at the workplace including bidirectional learning processes for experienced workers and new workers;
- **Synchronisation** of educational programmes with ICT future industrial needs;
- **Dealing** with the demographic changes: age-appropriate learning and training strategies are not yet considered;
- **Identification** of *Industrial Learning* best practices and their transfer to SMEs for an effective continuous training and learning process.

An *Industrial Learning* approach with relevant learning content, appropriate learning processes and delivery mechanisms is not sufficient if not adopted at a significant scale by manufacturing companies. To make a compelling impact on the skills of the manufacturing workforce, additional actions including raising awareness, dissemination of relevant information, and providing incentives for the adoption of *Industrial Learning* by companies, particularly SMEs, are necessary.

Manufacturing is Adopting the Circular Economy Paradigm

Since humans started using raw materials, natural resources have been depleted and the environment has been impacted. In the typical manufacturing environment, the so-called *linear economy*, natural resources are acquired from nature, used to make a product and disposed of as scraps in production or End-of-Life (EOL) Products. Due to degradation of natural resources, accumulation of waste, a larger world population and an increase the consumption of goods, humans need to address the long-term problem of an unsustainable economy for humans and the environment. Therefore, many countries are attempting to switch from a linear to a circular economy which is based on recycling and reuse of product materials to ensure healthy and safe living and working conditions. Contrary to the linear economy that is based on a *take, make, dispose* model, the circular economy aims to keep resources in use as long as possible and eliminate waste by focusing on products that are "made to last long and to be made again."
As with any business activity, environmental progress requires the use of appropriate tools. Sensors, data analytics, machine learning and blockchain are some of the new emerging technologies that enable and drive environmental actions in the same way they are driving business actions.

The Fourth Wave of Environmentalism

In light of the importance of adopting the circular economy, environmentalism is now at the forefront of manufacturing practices. A recent World Economic Forum report on work done by the Environmental Defence Fund concludes that these technologies are driving a *Fourth Wave of Environmentalism*.[44,45]
A new survey, commissioned by the Environmental Defence Fund, shows that 86% of executives from companies with $500 million USD or more in annual revenue agree that emerging technologies will help their bottom line results while at the same time improve their impact on the environment.[46] Over 70% of business leaders see greater alignment today between business and environmental goals than five years ago; 61% of them attribute this to "data-driven" emerging technologies; 80% believe consumers will increasingly consider companies as more responsible and accountable for the environmental impact of their products and of their processes.[47]
Recently IBM reported that Walmart, Unilever, and Nestlé are partnering with them to explore blockchain technology applications in food supply networks.[48] The emergence of these technologies provided Walmart the tools to set an ambitious goal of cutting 1 billion tons of CO_2 from its global supply chain-more than the annual CO_2 emissions of Germany.[49] Walmart is now working with more than 400 suppliers to make this reduction. This is only one example of how the *Fourth Wave of Environmentalism* has the power to drive solutions to large scale with impressive impact.

Reframing Digital Innovation for Deep Circularity and Desirable Futures

Carlos Alvarez-Pereira
President of Innaxis Foundation, Member of the Executive Committee of the Club of Rome

The adoption of the Sustainable Development Goals (SDGs) by the United Nations in 2015 has been a landmark in global agendas, for governments as well as for the private sector and society at large. It is now widely recognised that humanity faces a self-inflicted existential threat. In a synthetic manner, we have to move pretty fast to a regime of:

High Well-being @ Low Footprint

which in practical terms means two different paths of evolution, depending on which starting point each country or community is, to achieve:

Higher Well-being @ Low Footprint, or

Lower Footprint @ High Well-being

Footprint goes of course beyond the carbon one to include the many dimensions of our unsustainable consumption of natural resources. And well-being is not about individual affluence, it encompasses how wealth is fairly distributed and the health of communities is restored and flourishes. Nowadays some processes certainly contribute to these overarching goals, but the contrary also happens and overall, the net balance is that we are heading fast in the wrong direction, increasing the chances of collapse by not fulfilling the promise of sustainable development.

Needless to say, manufacturing is a central piece in the path that human civilisations have taken in their relationship with the biosphere and in producing material prosperity. Hence, the transformation of manufacturing in the 21st century has also to be central to a reconciliation of human development with the requirements of sustainable and equitable life for all (including all forms of life and the planet at large). While industries are under all kinds of pressure to keep their business going and remain competitive in a more uncertain world, how can they live up to their role in the shift we need?

In this context it is trivial to say that the shift requires innovation. This is generally extrapolated as a strong hope that technological innovation as it happens today will produce the shift. But while the kind of innovation we have is of course producing changes in society and in particular in manufacturing, it is far from granted that it will produce the right kind of changes we need. Taking digitalisation as the most publicised example of transformation driven by technology, we can ask if it is making humanity more compatible with life at large and creating the conditions for better preserving it. Although these questions have been rarely investigated, chances are that the answers are not so good as we could expect. The digital industry is a large and fast-growing consumer of all kinds of natural resources and energy, as well as a producer of GHG emissions and waste at an accelerating pace. And while digitalisation can be used to promote sustainability in industial sectors (f.i. through energy efficiency), the effects of these applications seem to be surpassed by the mass consumerism driving the digital sector itself (as a reference, 1.5 billion mobile phones were produced worldwide in 2015). Not to speak about the implications of digitalisation in terms of unemployment, social inequalities and concentration of wealth.

The framing of digital innovation

As shown in Figure A, although its dynamics include many different elements, digital disruption is actually conceived as a linear path.

The process starts with publicly-funded, top-down scientific research, then goes to innovation funded by venture capital and ultimately reaches commercial monopoly in a handful of cases. At early stages short-term financial profitability acts as the dominant selection mechanism and the final outcomes are failure in most of the cases and, in one per category, rentier exploitation of a one-player-wins-all dominance. This makes innovation as practiced today very ineffective as far as societal challenges are concerned. It can even create an illusion of debt-driven growth which does not fulfill its economic, social and environmental aspirations. Financial profitability is a one-dimensional, reductionistic metric unable to provide the right incentives to cope with the infinite dimensionality of the complex challenges we face. In that linear, ideal scheme, the societal challenges can only be expressed through market exchanges, while the very nature of citizenship is absent *and the harmful consequences of technology are considered as externalities, which means that taking care of them is left out of the picture. Typically it will be the role of nature, of people in poorer countries or in some cases of the State to clean up the collateral effects of technology. Or these will become the foundations for the next wave of technological "solutions": are these solutions to problems or just "solutions" looking for problems, as well as the "solutions" of today becoming the problems of tomorrow?*

Deep circularity.

We propose a new concept to face the challenge of how to make innovation, and in particular digitalisation, an effective instrument to achieve sustainable development. Of course this concept is related to the idea of the circular economy, of making economic processes more circular in their use of natural resources and their production of waste. But it goes deeper into the way we structure the social processes leading to innovation, whether in manufacturing sectors or in society at large.

Figure B is an attempt at reconciling the idea of conscious, purposeful innovation processes with the complexity of the world, in which simplest cause-effect relationships do not exist, feedback loops abound and process logic dominates over linear goals. The overall challenge we face can be summarised in that we need to find a way to recognise the full interdependency of our well-being at every scale with the biosphere at large. Achieving that recognition in a human way requires raising the levels of well-being of most of world population without increasing much their ecological footprint, while at the same time developed countries reduce dramatically their footprint without major damage to their levels of human development.

The combination of scientific knowledge and technological sharpness has a strong generative capacity, which could lead to many different global scenarios, to unsustainable ways of life (as today) or to the emergence of vibrant ecosystems for the benefit, diversity and sustainability of the biosphere. We have to prove, now and urgently, that sustainable development is not an oxymoron. The role of technological innovation in that mission seems critical but is not granted. For now, some seeds are being planted, initiatives such as "Computing within Limits", "Slow Tech" or many local projects truly using digitalisation to promote sustainability. But transformation research does not explain yet how to go from local seeds to a global change, and to a large extent technological innovation is right now captured by short-term speculation, not driven by societal challenges, focused on "solutionism" rather than on interdependencies, and produced without an active involvement of stakeholders. So, it may not help to drive our course away from socioecological disasters. Overcoming this requires co-creating desirable futures, and this will certainly mean reinventing manufacturing. We believe that the concept of circularity applied to the process itself of innovation could be one of the foundations of new frameworks helping in that direction. It could enable mutual recognition and cooperation between digitalisation and sustainable development as a significant effort to harness the power of innovation for the progress of humanity.

Figure A *- The social framing of digital disruption*

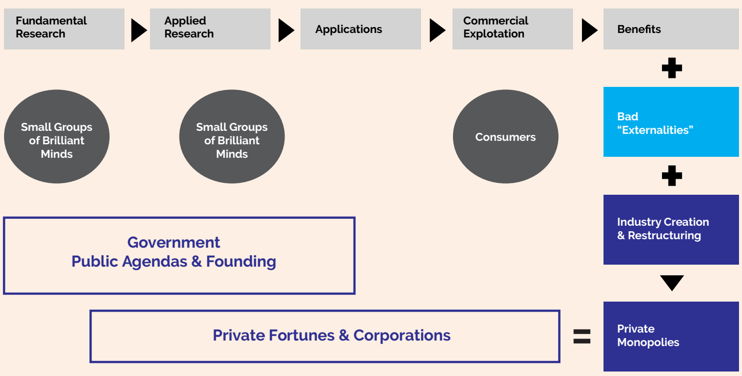
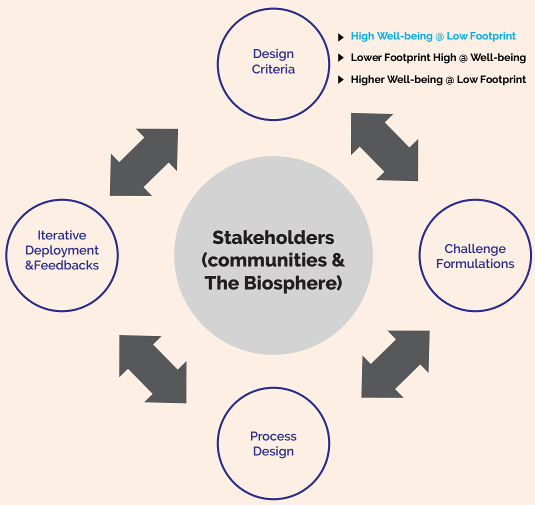


Figure B *- The co-creation of desirable futures*



Megatrends & Challenges

Societal Megatrends

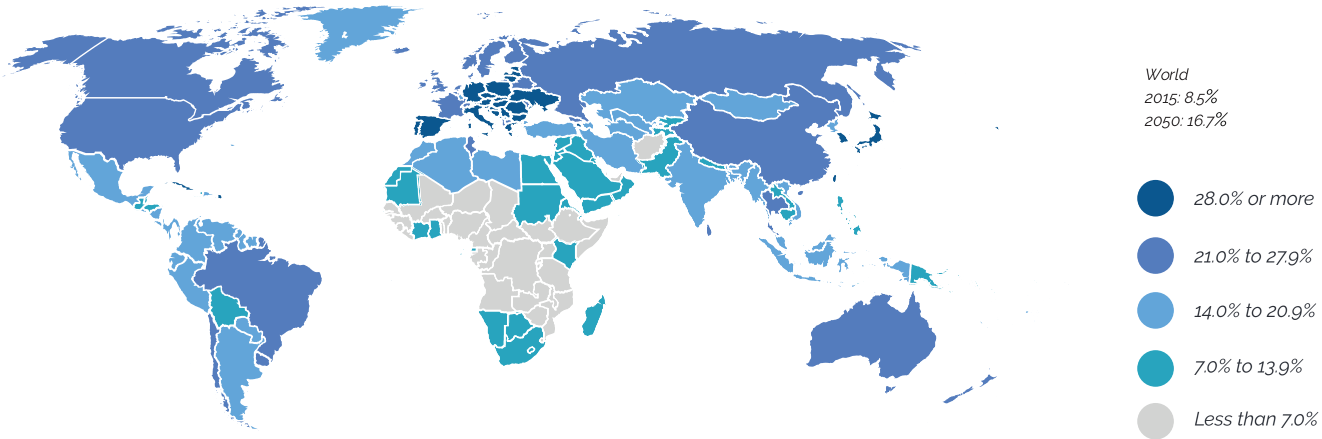
Manufacturing stakeholders, along with all other global citizens, will be influenced by broad societal megatrends that will shape the future trajectory of the world. The trends discussed in this section not only affect business and industry but will have a profound impact on society and overall human development. It is important to understand these broader changes that will require adaptation in the industrial sector in order to meet the needs of society. While the future is uncertain and forecasts cannot be too deterministic, it is important to analyse information and data to prepare for likely possibilities. These megatrends represent changes that the global community will need to address with international cooperation and innovative practices in order to build a sustainable future. The trends below have been selected based on importance and relevance to manufacturing and overall industry, though the list is not exhaustive. Through understanding and evaluation of societal megatrends, the manufacturing community will be better able to address societal needs and contribute to advancing human progress and creation.

Demographic Changes

Ageing Population

The future trends of demographic changes will prove to be a challenge for society. One of the largest shifts in global demographics will be the ageing population. By 2050, the percentage of the population aged sixty-five and over will increase dramatically, accounting for almost one-third of the population in some countries and particularly increasing in developed nations (See Figure 14).[50] This substantial increase will have profound effects on the workforce and societal demands. As the population ages, not only will there be a greater demand for senior care but a greater dependency will be placed on peoples aged fifteen to sixty-four. According to the United Nations Industrial Development Organisation (UNIDO), the ratio of the population aged sixty-five plus to those aged fifteen to sixty-four will approach close to 50% in regions such as Europe.[51]

Figure 14 - Percentage of Population Aged 65 and Over: 2050
(Source: UNIDO)



Further, research shows that the majority of the ageing population will not participate in the labour force, placing an even bigger strain on those aged fifteen to sixty-four (See Figure 15).[52]

In addition, there is a large global and regional disparity in the ratio of senior women who are active members of the workforce.

This low participation rate has a further adverse effect on overall workforce efficiency and equal representation within the workforce.

Due to the smaller ratio of young workers in comparison to overall population, gaps in the workforce left by the ageing population will be more challenging to fill. Consequently, there will be a greater need for a populous workforce to not only meet overall global demands but to also provide critical care services and manufactured products necessary for the ageing population.

Figure 15 - Labour Force Participation Rates for Population Aged 65 and Over by Sex and World Region: 2010 Estimates and 2020 Projection
(Source: United States Census Bureau)

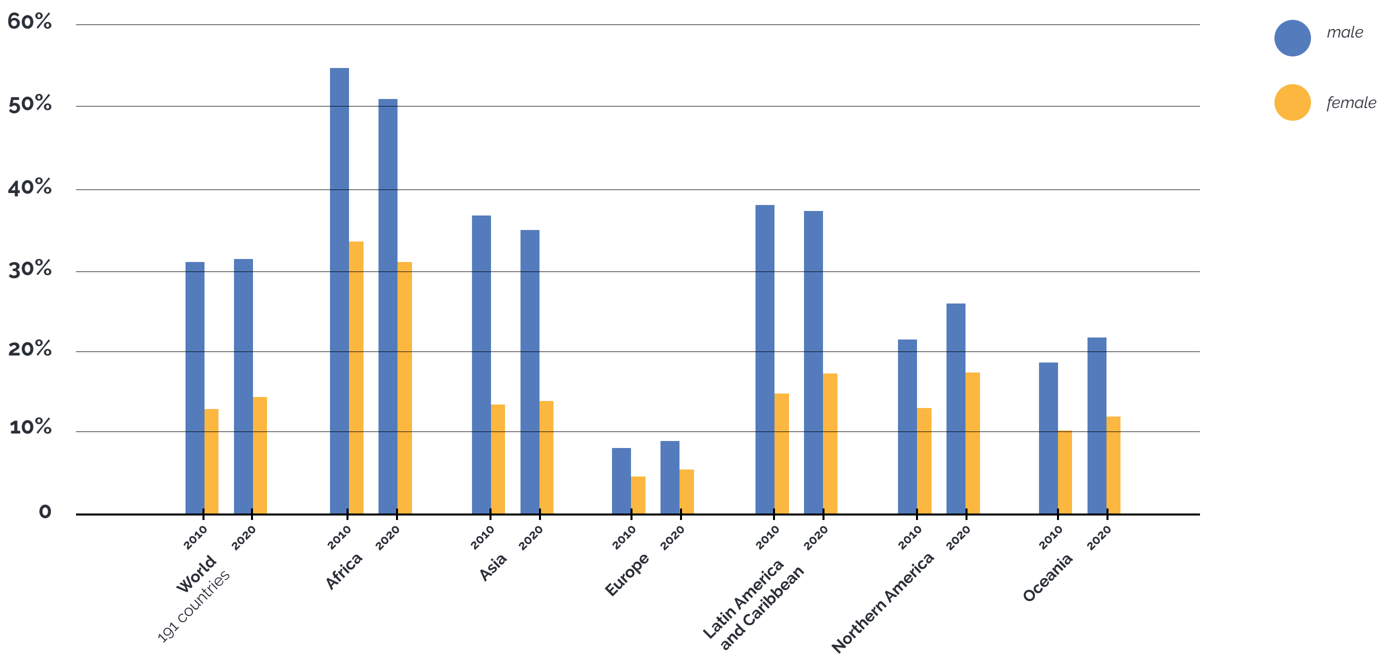
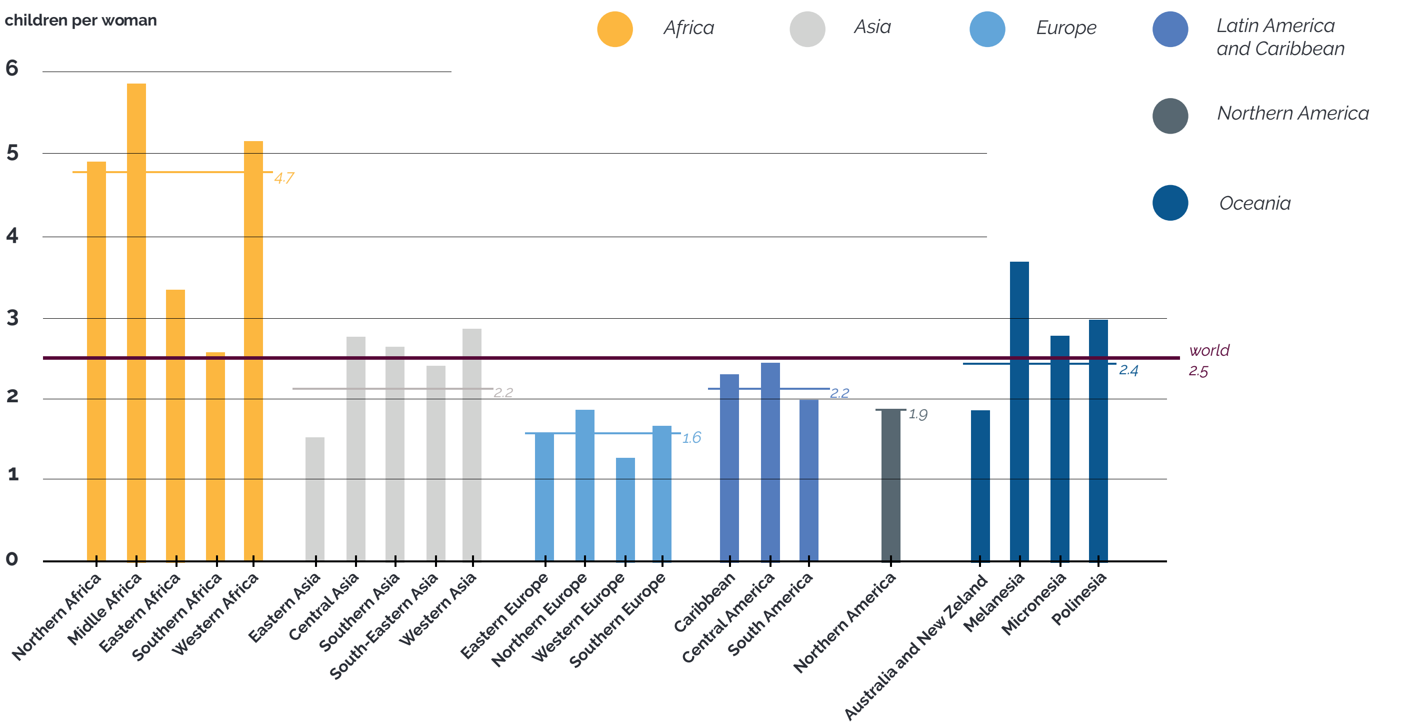


Figure 16 - Total fertility by region and major area, 2010-2015
(Source: United Nations)



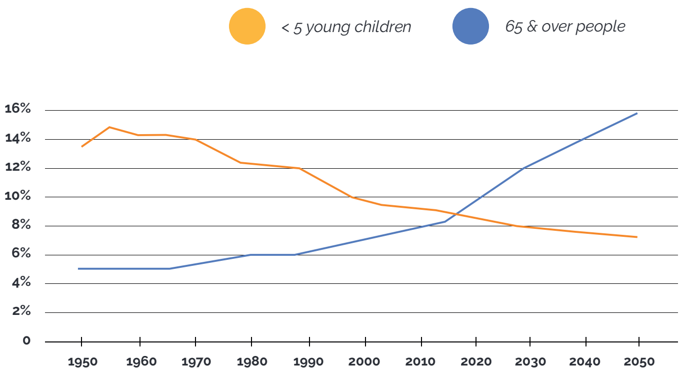
While coming-of-age children entering into the labour force will in time help meet workforce demands, fertility rates are being greatly outnumbered by the ageing population. By 2050, the global population aged sixty-five and older will be more than double that of children under the age of five.[53] Even more, population growth remains high in the forty-seven nations designated by the UN as “Least Developed Countries” (LDCs) and are expected to almost double in size to 1.9 billion people by 2050.[54] Conversely, fifty-one of the most industrially developed nations are expected to decrease in population by 2050, some by almost 15%.[55] All of these factors contribute to the challenge of maintaining an industrial workforce in the midst of an ageing population in order to meet the evolving needs of the global market.

Generational Gap and Lack of Young Talent

In a world of globalisation, digitisation and rapidly changing technologies, lack of young talent is a great concern for future society. New, diverse, and adaptable workers are necessary for the future digital workforce to succeed and lack of talents is a growing issue. In general, fertility rates in many industrially developed nations are greatly declining and almost half of the world lives in below-replacement fertility level countries (See Figures 16 and 17).[56] Over time, this will result in a smaller workforce needing to provide for a larger population and face the challenges of adapting to new technologies. As the ageing population retires, less workers and less young talent will be available to lead the digital revolution.

In addition to a smaller pool of young talent, poor allocation of workers and changing skill needs have resulted in a lack of talent in many STEM fields. Research shows that there is a mismatch between the location of most STEM graduates in emerging markets and developed economies.[57] In particular, countries in sub-Saharan Africa and the Caribbean are losing many of their STEM workers.[58] African countries lose over 20,000 skilled workers to developed economies each year.[59] Without having an abundance of leading professionals present in developing economies, opportunities for teaching and mentorship are more limited. This misallocation of workers can be detrimental to emerging markets and fuel a further lack of young talent globally.

Figure 17- Young Children and Older People as a Percentage of Global Population 1950 to 2050
(Source: United Nations)



Further, a lack of women, rural populations, minority groups, disabled persons and economically disadvantaged persons in STEM fields create untapped talent pools that are necessary to spur innovation and keep pace in the digital world. Women represent only 30% of the world's science researchers and minority groups represent only 10% of STEM Workers.[60] By having such a large talent pool that is underutilised in the STEM fields, economic growth and innovation can be stunted. It is critical to ensure there is enough talent that can work to maintain and create new digital infrastructure.

Enhancing Workforce Diversity

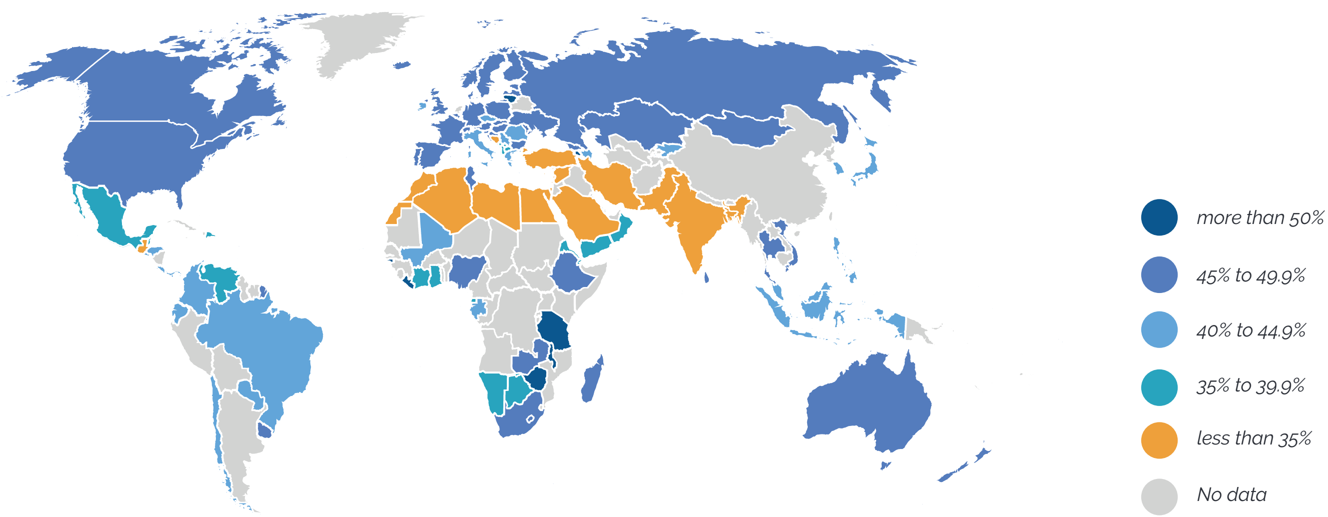
Enhancing diversity in the workforce is a megatrend that is shaping the future of work and industry.

As society works to meet the needs of the aforementioned ageing society and generational gaps, including and utilising all persons as productive members of the workforce is imperative. Even more, society and business both benefit from social inclusion and diversity. A Deloitte study has found that when employees believe their organisation is committed to and supportive of diversity their ability to innovate increases by 83%.[61] Further, a Harvard Business Review study found that teams are more likely to solve problems when they are more cognitively diverse.[62] Women, disabled persons, and minority populations are currently underrepresented in the global workforce and their inclusion is a key part of future trends.

Women

Training, employing, and maintaining a high number of women in the industrial workforce due to social exclusion and discrimination has proved a challenging societal effort. Throughout all industries, the employment rates of women compared to men is still significantly smaller and even more pronounced in industrial sectors such as manufacturing.[63,64]
As a result, women are still outnumbered by men in the workforce in almost all nations, particularly in LDCs, where population is growing rapidly (See Figure 18).[65] Having a smaller number of women in the workforce not only signals gender

Figure 18 - Female Share of the Labour Force
(Source: Pew Research Centre)



2018 WMF Report ***Case Study***

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO - Empowering Women in Urban Industries to Create Inclusive and Sustainable Cities

Mark Draeck
Industrial Development Officer, Energy Systems and Infrastructure Division, UNIDO
Katarina Barunica Spoljaric
Associate Industrial Development, Climate Policy and Partnerships Division, UNIDO
Nicholas Dehod
Project Associate, Energy Systems and Infrastructure Division, UNIDO

Approximately 57% of people living in Senegal reside in urban areas and this number is expected to rise up to 64% by 2050. Related difficulties in effective planning and integration of urban development will be most likely exacerbated by emerging climate change impacts, which will ultimately increase the vulnerability of cities.

Senegal generally requires skilled professionals in the industrial sector to create sustainable economic and social infrastructure. As such, the increased participation and representation of women in the sector is considered highly advantageous. To date, female participation in the industrial sector has been marginal, both at institutional and enterprise level, making it extremely important to advance women's contribution and influence in decision-making processes.

There is need to build women´s knowledge and capacity on the subject while ensuring support and mentorship structures to improve women's participation at all levels. This requires efforts aimed to remove the obstacles to gender equality and women´s empowerment in industry in general. It is necessary to showcase and promote women as agents of change and to build the institutional capacity for gender-sensitive governance and industrial policy development and implementation.

In fact, energy, resource efficiency and chemical and waste management interventions within the industrial context are not always gender-neutral. To ensure that men and women equally benefit from development projects and that inequalities are reduced or eliminated, gender dimensions need to be integrated throughout the project cycle – from design and implementation to monitoring and evaluation.

To this end, UNIDO has developed "Sustainable Cities Management Initiative for Senegal", a project within the Global Environment Facility's Integrated Approach Pilot that aims to improve the capacity to plan and implement sustainable city management practices. In partnership with the World Bank, UNIDO is improving livability in the new Diamniadio City with interventions for greening the production in the industrial park, integrating renewables and energy efficiency systems in the energy supply mix, and for sustainably managing industrial waste.

During the project's preparatory phase, UNIDO conducted a preliminary gender analysis of the country context as well as a gender assessment. The preparatory phase served to identify potential gender dimensions of project outcomes and outputs, as well as potential entry points for gender equality and women's empowerment. Implementation of the project will include several aspects: collection of sex-disaggregated baseline data; in-depth gender analysis of country, regional and sector context; mapping of partners, counterparts and stakeholders, identifying gender focal points, women leadership and/or gender policies and strategies; and inclusion of gender perspectives in the communication strategy/activities. These will be verified through a detailed analysis to be conducted during the project's implementation as well as during monitoring and evaluation. The lessons learned from this project will be scaled-up with the outcome of increasing the participation of women in the industrial sector across Senegal.

Inequality within nations but also lessens the talent pool of those in the labour force. Without a balanced and inclusive workforce, nations will have less talent to help spur innovation and move their economy forward.

Within the manufacturing industry, perceived gaps in gender equality often deter women from beginning or maintaining an industrial career. According to Deloitte's Women in Manufacturing Report, less than 15% of women surveyed believe their industry is accepting of family and personal commitments and over 72% believe they are underrepresented in their organisation's leadership team.[66] However, 42% of women do believe the pay gap between men and women in the manufacturing industry has been declining. If women are deterred from industry, there will not only be less representation but also less diversity in ideas and innovation which, ultimately will slow progress. The inclusion of women and all genders in the industrial workforce is a key megatrend that will positively impact the future of industry.

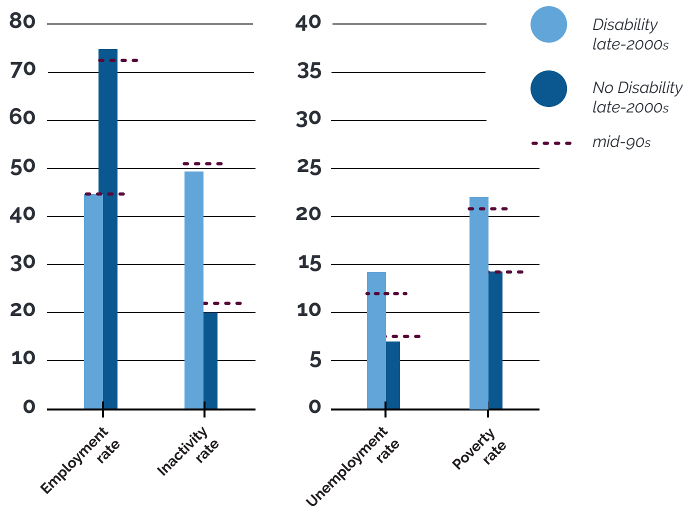
Disabled Persons

Persons with disabilities have low employment rates despite representing a large percentage of the global population. Over one billion people are estimated to live with some form of disability, accounting for approximately 15% of the world's population.[67] However, less than 6% of disabled persons have significant difficulties that would prevent them for engaging in the workforce. Even so, the employment rates of people with disabilities are still much lower than average employment and many are inactive in the labour force (See Figure 19).[68] This results in a considerable amount of the workforce being underutilised, therefore creating an environment that is not as inclusive or innovative as possible. In a time where more participants in the labour force are needed, it is crucial to provide accessible work environments to allow for diversity and inclusion. Creating accessible workplaces will need to become a priority in order to enhance workforce diversity in tandem with social inclusion.

Foreign-Born Workers

As globalisation and migration increase worldwide, the for-

Figure 19 - Employment Rates by Disability Status
(Source: OECD)



eign-born workforce has greatly increased, particularly in developed nations.

Despite the positive benefits of migration adding to the workforce, migrant workers can become some of the most vulnerable members of society being subjected to poor working conditions and unfair treatment.[69] OECD data shows that there are significant disparities in employment rates of foreign-born workers when compared to native employment rates.[70] In OECD countries, the foreign-born unemployment rate is 4.4% higher than native-born citizens.[71] However, labour participation rates are almost identical between native and foreign born workers in many developed economies around the globe. As nations face challenges associated with demographic changes, inclusion of migrants and foreign-born workers will shape the future of employment and productivity. Additionally, studies have also shown that foreign-born workers help to create more economic activity and those with higher levels of education will innovate and help to produce more domestic jobs.[72] Business will need to embrace this trend as globalisation and migration increase in order to add diversity and keep pace with changing demographics.

Digital Divide

Since digitisation plays a central role in the personal and professional lives of many in developed nations, it is key to understand the digital divide and trends relevant to future soci-

Democratising Manufacturing and Design: Fostering Localised Value Creation and Innovation

Thorsten Wuest
Assistant Professor, J. Wayne & Kathy Richards Faculty Fellow, West Virginia University
Ramy Harik
Associate Professor, University of South Carolina, SC, USA

The world is changing rapidly and with it the way we innovate, create and sustain. The main drivers of change are the Internet and the connectivity it brought forth. With the advent of the "Everything Connected" era, instant communication and information exchange became possible unobstructed by physical distance.

However, the real revolution with regard to new business models, innovation and value creation came with the transition to the web 2.0. This brought forward the ability for virtually everybody to create and publish on a global scale while revolutionising business, economic and technical opportunities. Previously, creation and distribution of content required technical expertise, limiting the number of people able to fully exploit many of the opportunities afforded to them via the Internet. New tools available for use on the World Wide Web enabled the proliferation of new tools that yielded highly usable and scalable architectures in a simplified manner lowering the technical barriers for entry into the new cyber-domains. The bottom line result is quite clear in hindsight: users can focus fully on value creation rather than technical details of implementation. History has demonstrated that unforeseen opportunities emerged that were associated with content creation, e.g., new careers such as 'influencers' and 'digital nomads'. Furthermore, where significant and well-grounded brick and mortar institution once stood, new virtual and cyber institutions rapidly supplanted them (e.g., Blockbuster to Netflix). It is often stated that the biggest hotel chain has no physical buildings (AirBnB), the biggest taxi company has no cars (Uber) and so on.

Manufacturing and design were also dramatically altered by this new reality. New technologies were introduced and products and processes rapidly evolved to become ever more efficient, effective and connected. In fact, it is not clear whether an evolution occurred, or a revolution occurred. Some name this revolution the Fourth Industrial Revolution or Industry 4.0, which in conjunction with concepts such as Smart, Cyber and Cloud Manufacturing are driving innovation, wealth and new business and economic models. While the line between the cyber and physical sectors is rapidly blurring, the overall development differs significantly from the development of the Internet in one key aspect: the expertise required (technical) to produce (innovative and creative) products and content of highest quality. The complexity of processes and design guidelines increased over time with the introduction of new technologies, processes and tools. The ability to create a physical part does require capital equipment, and process and product know-how that is traditionally gained over years of experience. Hence, large parts of the population are effectively 'locked out' of value creation.

Internet (R)evolution & Impact on Content Creators' Innovation

Drastic changes have been experienced in the access, consumption and production of information, as well as in communication in general. For the bulk of history, professionals created and made available information content to the public. Presently, content creation and sharing are virtually ubiquitous. In the early days of the Internet, a certain amount of tech-savviness and expertise was required to create (and access) information content. However, since the dawn of the so-called web 2.0 and modern easy to use tools and services, such as WYSIWYG editors (e.g., TinyMCE, GoogleSites), social networking services (e.g., Facebook, Twitter) and search engines (e.g., Google, Bing), there is little to no baseline expertise required for content creation and dissemination, significantly lowering, if not eliminating, barriers to market entry. This development had a tremendous impact on the economy, especially in the United States, with entrepreneurs creating new businesses, business models and even completely new careers. Of course, the new technologies and new uses of these technologies give rise to a new set of challenges. For example, cybersecurity is an issue with ever changing threats. Issues such as "fake news" (or data) can lead to a lack of information integrity in operations. A less threatening, but still critical issue is reduction of the effects of distance which has many implications including the ability to take advantage of tax motivated registration of corporate headquarters, which can have both, a positive (e.g., *equalised opportunity for service jobs) as well as negative impacts (e.g., competition from e-commerce) on local economies. While there are similarities between the manufacturing and Internet domains, there are also distinct differences. Similarities include a focus on cybersecurity and the importance of big data and data analytics. However, the differences are quite distinct including manufacturing's reliance on significant capital investments, training and local facilities, safety and required expertise. In some instances, some of these highlighted differences do have some overlapping aspects; however, they take on somewhat different forms. An example is (product) liability where "Internet" liability considerations, often monetary in nature, differ significantly from a physical manufactured product which may directly cause serious bodily harm if certain product functions fail.*

Challenges of Democratising Manufacturing & Design

A fundamental change in manufacturing to make it more accessible, as envisioned in this discussion, comes with a variety of challenges. One major challenge is that the manufacturing industry is rather conservative and often requires substantial capital investment, and time for manufacturing operations to scale to significant production levels. Associated with this is the safety aspect. When an "outsider" is designing a new product and associated manufacturing plan which is directly executed on a certain machine tool, it needs to be ensured that the plan will not lead to damage on manufacturing machines and equipment or even injure shop floor workers. Today, the machine tool owner is taking on this responsibility by being an integral part of the design and manufacturing process. In the vision, the direct access requires some form of brokerage to overcome this hurdle. Another issue is the liability of the final product during usage. Again, who is responsible when functionality is not as planned based on flawed design (assuming there was no manufacturing error). In all these cases the question arises: who is responsible?

Another challenge is how Intellectual Property (IP) is managed. Who owns the IP (or what is a fair share) for a design that is heavily supported by a software package? This leads to another overarching challenge: Old business models will not be suitable any longer and need to be adapted or replaced. There are many technical challenges not considered in this paper, including interoperability, computational, dynamics and complexity.

Benefits of Democratising Manufacturing & Design

Significantly reduced "waste" in terms of different people essentially designing the same (or very similar) parts over and over again is a major benefit. Through a comprehensive "search function" for parts/components/features including easy alterations, experts can focus on new, worthwhile designs. By providing the opportunity to innovate and create new products for everybody, many new and previously unimagined solutions can be expected. As the new content creators are not trained in engineering design, new and unbiased ideas may spark. This has the potential to revive local, small-scale manufacturing by connecting local SMEs to content creators. A benefit that has an impact on more than just this vision is the possibility to use existing expertise more efficiently, less dependent on time, location and 1-on-1 interaction. Further, if the internet revolution is any indication, many benefits will emerge once these tools are provided to content creators that we cannot imagine at this point– including new business models, products and careers.

Manufacturing and design are a core part of every industrialised economy. However, large portions of the citizens are effectively 'locked-out' of creating new innovative products due to a lack of expertise and easy to use tools, while manufacturing becomes more and more complex. This development differs from the internet revolution and how it provided the foundation for countless new business models, allowing non-experts to create content and innovation at scale. The question is, can we initiate a similar development in manufacturing? We compared the two domains, presented benefits and challenges as well as identified requirements including a brief overview of current approaches.

We believe that by reducing the entry barrier and by providing people with the initial means to truly "create" sophisticated manufactured products, new opportunities will flourish and entrepreneurs will find ways to develop novel business models. Similar to developments in other domains, it is essential to show the potential of such a solution and how key issues can be successfully addressed with scalability and extensibility naturally built-in. Once this is achieved, the competitive marketplace will pick it up and develop new solutions addressing specific needs, address the usability that is required to reach a large portion of users/content creators and stimulate the growth to critical mass. This will truly be a democratising force that will lift manufacturing and design to the next level and by increasing participation of previously untapped groups spurring creativity and innovation.

ety. In a relatively short period of time, digitisation has rapidly advanced throughout the world. The World Economic Forum estimates that now 94% of the global population can receive a mobile phone signal and 50% can receive a mobile internet signal. However, only 36% of the population subscribes to a mobile internet provider.[73] While these figures show a high rate of adoption, usage still varies greatly by region and socioeconomic class. In sub-Saharan Africa, only one-third of those with access to 3G capabilities are using the technology.[74] Affordability and relevance are two issues still at the core of the digital divide. In some areas, internet access can cost upwards of 10% of monthly income and content available via the internet are not of great relevance to users.[75] The Global Information Technology Report's Network Readiness Map illustrates regional disparities through mapping network access throughout the world (See Figure 20).[76]

Further, as disparities grow between countries with regard to technological infrastructure and use, there is a risk of digital divide leading into cultural divide. Since the majority of knowledge in developed nations is accessible through digital technology, LDCs cannot as easily attain the necessary knowledge as more developed nations. This can result in skills gaps and lack of competencies that further hinders progress and growth of LDCs and even fuels a larger cultural, social and economic gap.

The digital divide not only varies throughout regions based on socioeconomic status but it also is apparent throughout age and gender. Young people aged fifteen to twenty-four make up over a fourth of total internet users globally.[77] Over 71% of young people are using the internet compared to just 48% of the total population, and this disparity is even more pronounced based on geographic area (See Figure 21).[78] As young people greatly outnumber other internet users, a digital divide exists generationally making the internet heavily dominated by younger users. Even further driving the divide is gender disparity in internet access. Men outnumber women using the internet in over two-thirds of nations.[79] Though the digital divide has improved over time with greater adoption, this trend must continue and be embraced throughout the globe. In order to fully embrace the digital world, access to the internet for LDCs, all generations, and between genders must be improved.

Cybersecurity

With increased digitalisation in the workplace, businesses, particularly industry, are more vulnerable than ever to cyber-threats and cyber-attacks. It is estimated that the total cost of cyber-crime in the global economy could be as high as $500 billion USD.[80] Companies will need to spend a considerable amount of money to protect their digital infrastructure, employees, and sensitive data from cyber-attackers or risk worse financial ramifications. In the circumstance of a cyber-attack, companies of all sizes will incur large costs to repair breaches but will also face losing sensitive information including trade secrets and intellectual property.

Figure 20 - Global Internet Access
(Source: Global Information Technology)

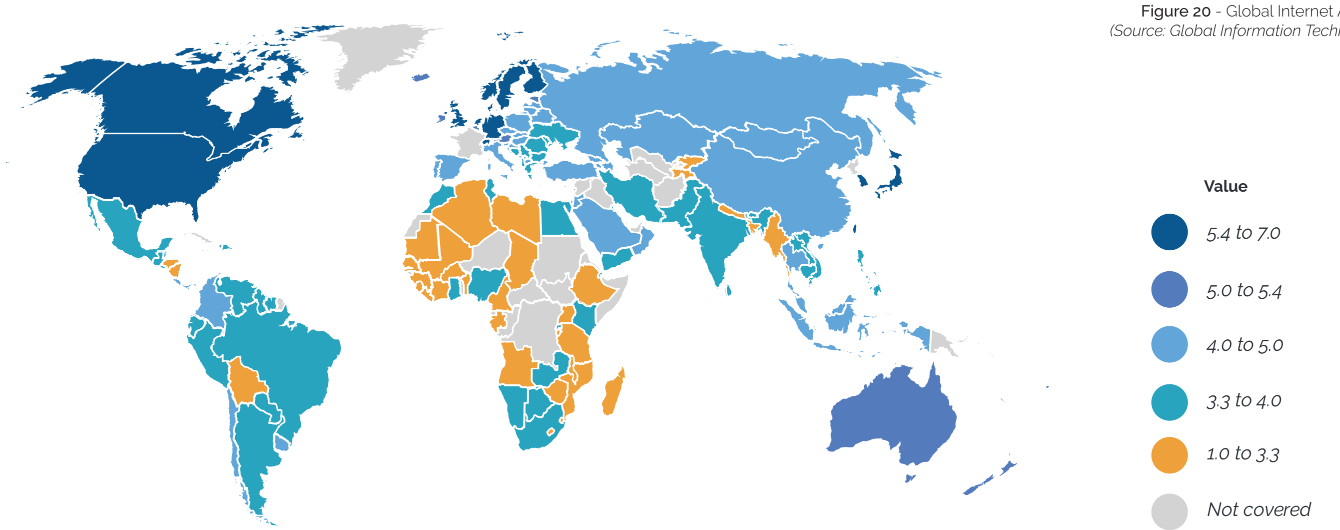
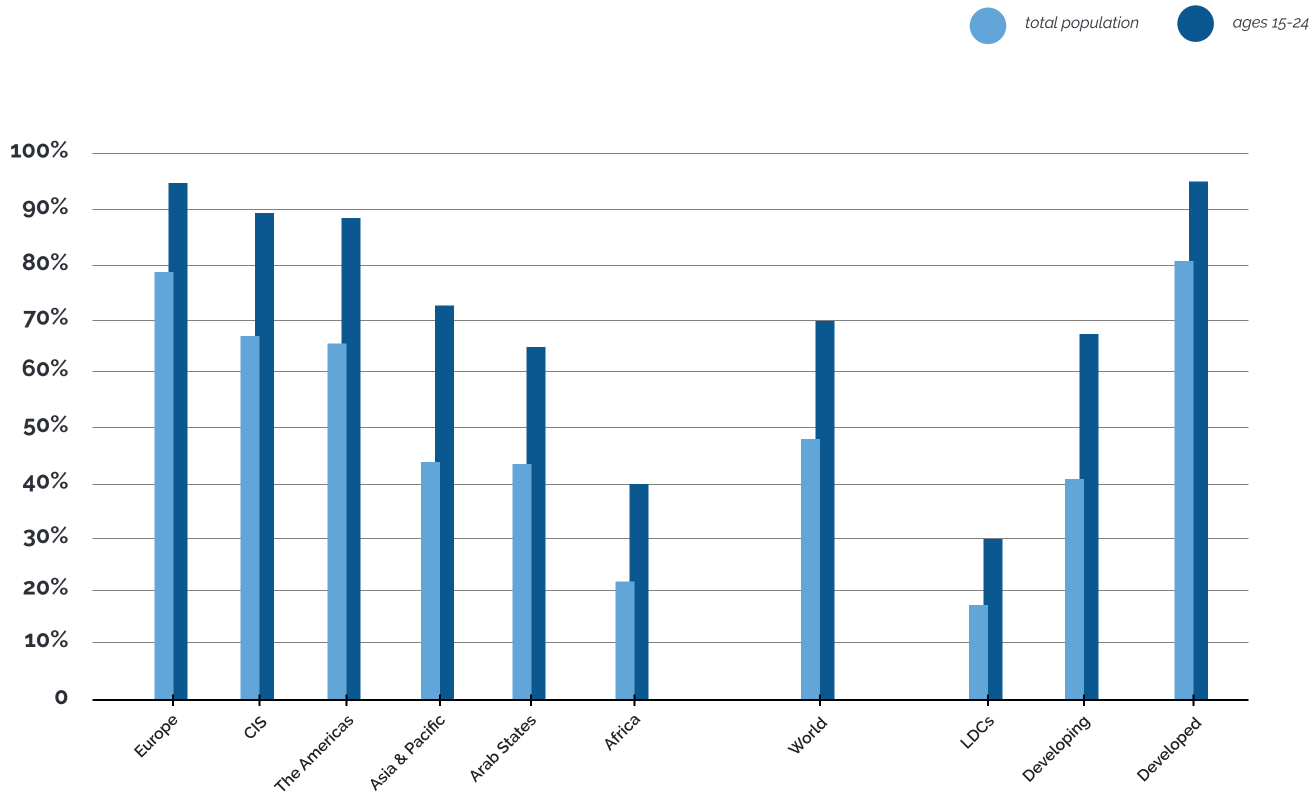


Figure 21 - Proportion of Individuals Using the Internet, By Age, 2017
(Source: International Telecommunications Union)

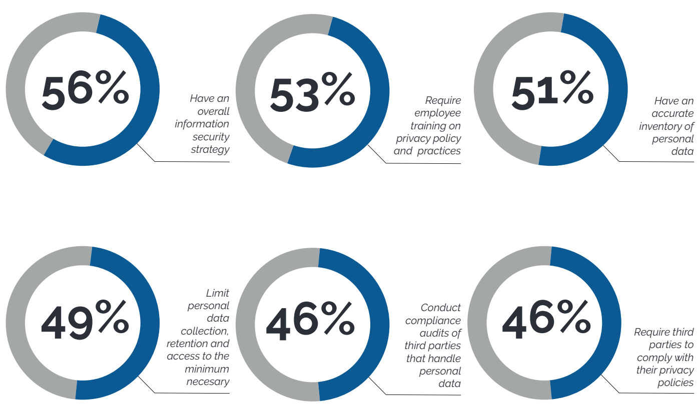


While businesses can take measures to protect against cyber-threats, companies are having to rapidly advanced their systems. Although businesses often lack the technical knowledge and expertise to protect advanced systems. The PwC Global State of Security Survey finds that only 56% of companies have an overall information security strategy (See Figure 22).[81] Companies are not able to fully or easily invest in their cybersecurity measures and therefore cannot carry out best practices, leaving both the company and employees at risk. Most companies have not put key measures in place leaving them both vulnerable and without talent to efficiently manage these security measures. Cybersecurity providers, particularly those who are third-party, will have greater demand despite difficulty to find talent in order to satisfy the market.

While digitisation has become a regular part of everyday life, personal information that is contained in various outlets and platforms is also left vulnerable to attacks. The digitising of the world will require changing attitudes and increased security measures to evolve alongside technological progress.

The Facebook and Cambridge Analytica case is a well-known example of how a large quantity of personal information can be harvested and misused. Over 87 million Facebook profiles were harvested for private information that was used to help target US voters during their 2016 presidential election.[82] This data breach is one of many signals for the need of cybersecurity measures both within institutions and personal life as a future megatrend.

Figure 22 - PwC State of Security Survey
(Source: PwC)



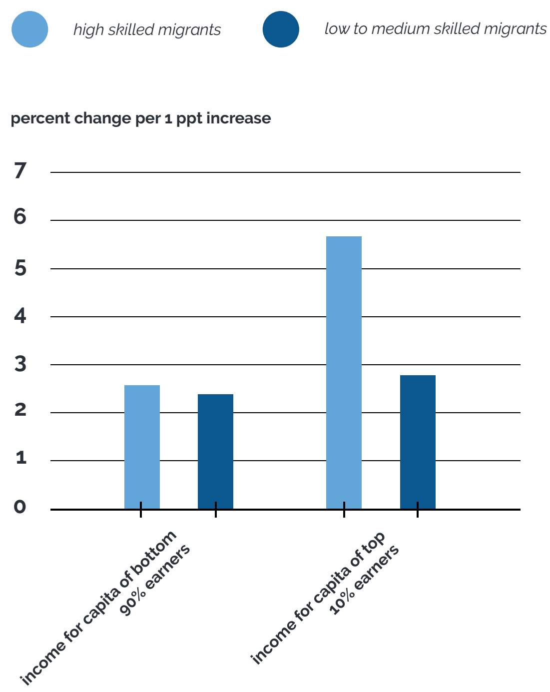
Urbanisation

Worldwide Migration

Throughout the world, migration is significantly increasing. While this introduces workers with new skill sets, adds to the workforce of certain nations, and helps to shape economic development, the effects of migration will present a challenge for both industry and society as a whole. In 2017, there were 258 million international migrants, compared to the year 2000, when there were 173 million.[83] However, two-thirds of the 258 migrants in 2017 were spread out over only twenty countries (See Figure 23).[84]

These shifts in population will not only affect the workforce but will also create greater demand for certain manufactured goods and diverse products in nations that have the highest number of migrants. Population, industrial trends and societal demands change greatly with significant numbers of migrants in the adult population. This will shape the industrial trajectory in many nations, particularly those where national income per capita is in the top 10% of global earners (See Figure 24).[85] For nations with high numbers of migrants, there will be greater societal demand from both government and industry, whereas nations that are losing migrants or receiving few will have to domestically train and source workers in order to meet societal needs.

Figure 24 - Effect of Increase in Share of Migrants in Total Adult Population
(Source: International Monetary Fund)



Growing Urban Population

The world urban population is growing rapidly in industrialised areas, bringing to light complex issues of sustainable development within economic, social, and environmental contexts. Currently, 54% of the world population lives in urban areas. However, by 2050, this figure is expected to increase to 66% (See Figure 25).[86]

Figure 23 - Average Annual Rate of Change in International Migrants by Country or Area of Destination 2000 to 2017
(Source: United Nations)

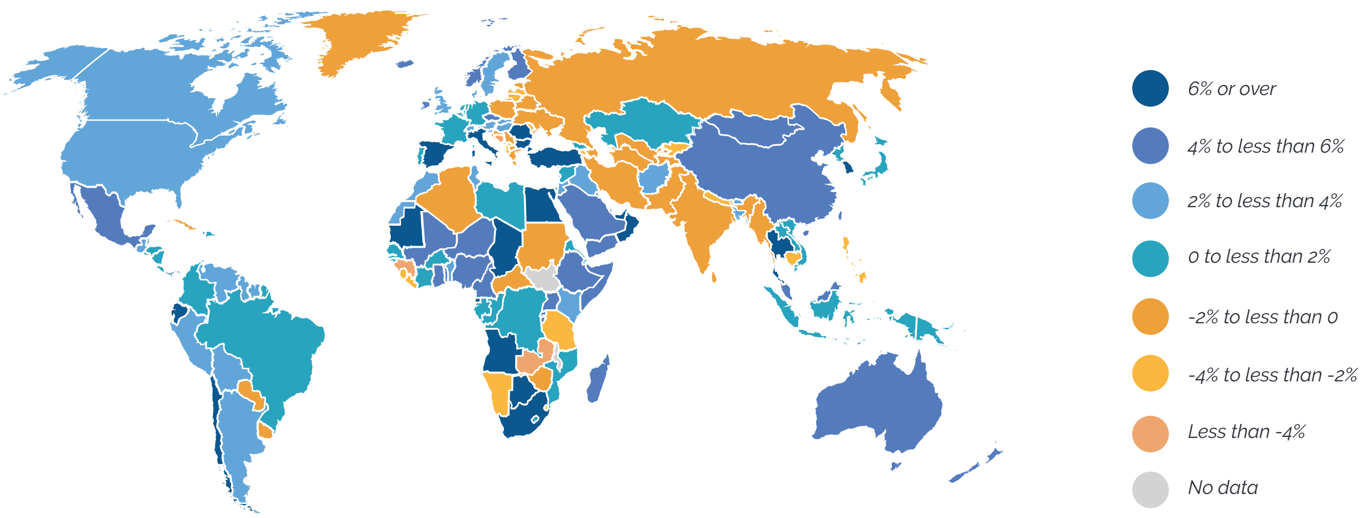
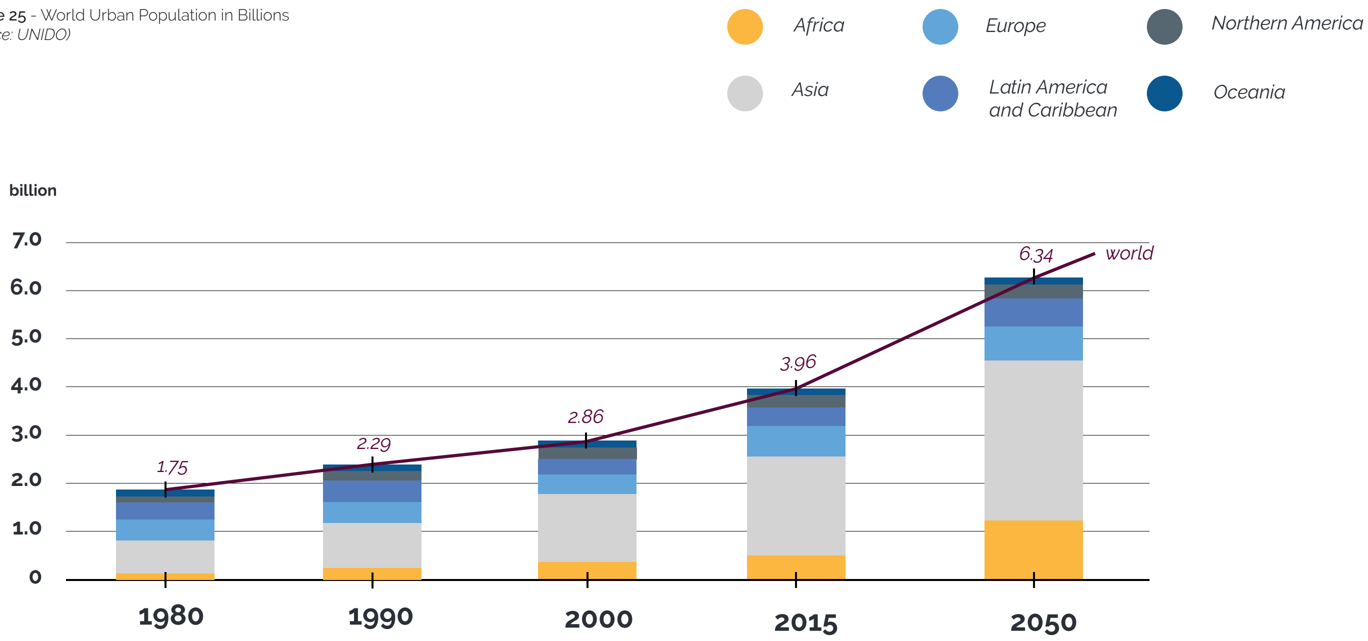


Figure 25 - World Urban Population in Billions
(Source: UNIDO)



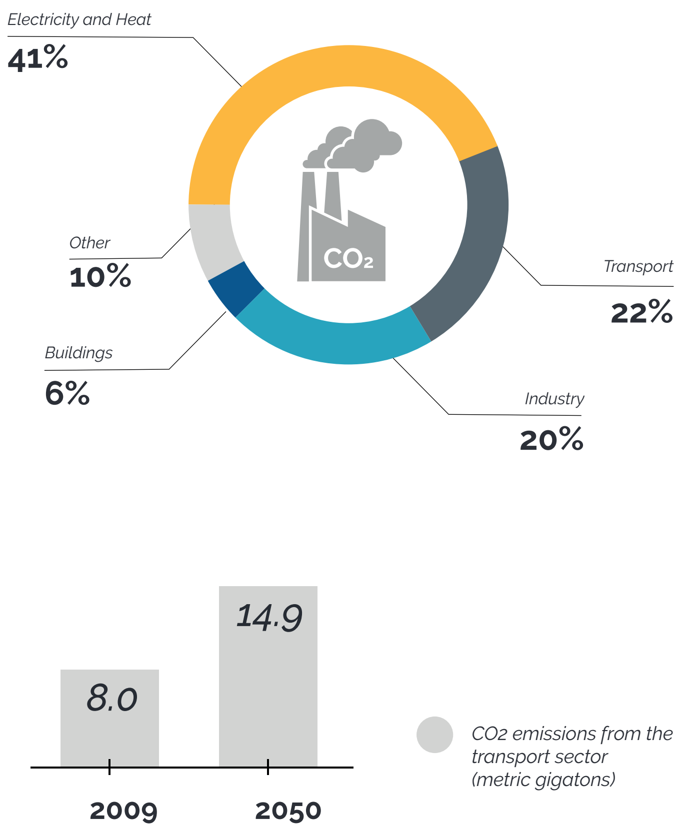
This large increase of population in urban areas will place greater demand on the workforce since there will be a higher concentration of people that will need goods, services and care. Particularly, those with low to middle income wages respective to their city will have the highest needs. Consequently, there will be a greater demand for manufactured goods in urban locations especially in the areas of infrastructure, value chains, transport, energy, and telecommunications. Industry will need to find solutions to meet the needs of the majority of the world that is living in urban areas in order to provide adequate resources for all. Additionally, the increasing urban population will require mobility solutions to transport people through larger, more populous areas while still maintaining environmentally friendly practices both in production and use of manufactured transportation. While global revenue for transportation related services will continue to increase, CO2 emissions will almost double by 2050, calling into question the utilisation of clean energy (See Figure 26).[87]

Environmental Megatrends

Climate Change

Perhaps the greatest environmental challenge for future society is the phenomenon and effect of climate change on our earth. Carbon dioxide levels in the atmosphere are drastically

Figure 26 - World CO2 Emissions by Sector in 2010
(Source: Siemens)



New Urban Manufacturing Ecosystems as a Way to Foster a Mission-Oriented Development Model: Milan Case Study

Stefano Maffei
Director of Polifactory, School & Department of Design, Politecnico di Milano

Nowadays, it seems clear that the manufacturing discourse is facing a considerable debate about the new drivers of its transformation. The idea that manufacturing activities could be linked only to a traditional scenario of places (the factory), processes (highly integrated large/medium scale processes) and actors (the specialised manufacturing system) has progressively faded away. The idea of a shared and unified conception of what the term industry represents is changing fast; first of all, discussing the balance between the economy of scale and the economy of scope principle. The maturity of consumption systems of advanced economies, the new questions posed by the crises generated by the inevitable challenges of climate change and the future of work in an increasingly automatised production-work environment creates an entirely new opportunity for shaping the socio-economic, organisational and technological model of innovation for the productive sector.

The game field is also new. The idea of production, which is only shaped by the forces of globalisation, is mutating to also involve the idea of having meso-level networks of integrated actors, processes, systems that act on a regional, local and metropolitan scale.

These new emergent forms of productive activities do not involve the single enterprise destiny, as it is imagined and narrated in most of the Industry 4.0 rhetoric. However, they could be applied to new clusters/networks of enterprises.

The scale on which this new perspective appears is that of the city. At this level, it is possible to understand that manufacturing is not an abstract sector of human-technological activity regulated solely by a dominant market logic but a complex and interrelated socio-technical world which is wholly connected with the socio-political perspective.

This is why it is essential to consider the manufacturing activities within Marianna Mazzucato's frame of mission-oriented research and innovation.

If adopted, then a new idea of manufacturing as a public/private side and cross-disciplinary development model that will emerge. This model can tackle some critical societal challenges such as local/regional development models, new employment, new skills, circular economy and sustainability, future city growth, production-consumption models and environmental challenges.

The city has become the centre of a scene which is the focus of a growing number of policy actions that are not only affecting the former "industrial policy", but rather adopt the idea of metropolitan areas as the engines of social and productive change. Cities concentrate both the demand of product-services, technologies, and physical-digital infrastructures along with the economic, political and organisational resources, knowledge about the environment, physical spaces, and the offer made of competences and individual and collective skills, the research infrastructure (private and public entrepreneurship, universities, labs, research institutions) and the possible production-distribution infrastructure that serves the everyday metabolism of the city.

The city itself is also a vast innovative market made by both public and private actors plus the citizens that are deeply rooted in its physical and social structure. This market could be developed by structuring an innovative distributed productive system that would be embedded within the city systems and which could be integrated within the existing infrastructure.

Not only: city is the unique scale/spot in which it is possible to put together a transformational direction in terms of directionality and intentionality of this change and connect it to a systemic or challenge-oriented policy scheme.

Milan has already fostered this mission tacitly through the EXPO 2015 action, which has reinforced and empowered the system made of public and private institutions, enterprises, universities and research centers. This was seen explicitly through a series of urban policies that supported the birth of new communities of innovators (made of professionals, new entrepreneurs, active citizens and communities) and the *reinforcement of social, economic, technological, and cultural milieu through the creation of spaces for digital fabrication (makerspaces, fab labs, co-working spaces) along with a rise in awareness and networking.*

Milan has been transformed into an open city-laboratory that might fit into a Fab City vision. Starting from its tradition as an industrial city based on its relations with the industrial districts in the north of Italy, it constituted the scaffolds for Made in Italy sectors. Milan has consolidated its manufacturing infrastructure with nearly 36,000 enterprises, 350,000 jobs and 13,000 craftsmen involved in the manufacturing ecosystem along with a rapidly growing number of startups (approximately 25% of the city overall turnover).

The city has characterised itself as the fashion and design capital for a high density of creative and technology professionals, enterprises and of the design and fashion system (made by fairs, events and cultural initiatives).

Plus, Milan has a great concentration of co-working spaces, fab labs and makerspaces (more than ten), a large number of incubators, (private and public) many creative hubs related to a public-private research and a university system well connected to the entrepreneurial environment.

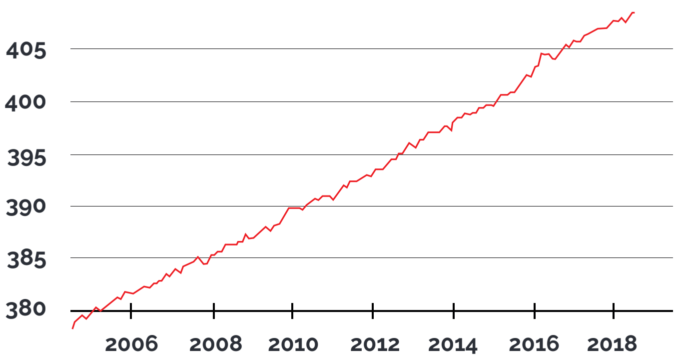
This connected ecosystem is extremely able to imagine, develop, materialise new products-services in the high value productive chains such as agri-food, fashion, digital transformation and communication, healthcare and med-tech. The Municipality has developed a policy of incentives for building a distributed digital manufacturing infrastructure made of fab labs and makerspaces, coworking spaces, startup incubators and projects dedicated to research and experimentation on innovation models including pilots on an urban scale (OpenCare, OpenAgri) and capability building for individuals to develop digital skills in young people (Mi Generation Lab).

Thanks to this significant concentration of resources and opportunities, Milan has been able to issue a mission-oriented policy dedicated to building new manufacturing model: ManifatturaMilano (www.manifattura.milano.it). This policy action is focused on building an urban manufacturing system and infrastructure through the sustainance given to the new digital craftsmanship actors and experiences.

The action was also inspired by the ten points of the Fab City Manifesto (https://fab.city/documents/Manifesto.pdf) in which the productive city must be ecological, inclusive, locally-productive, people-centred, holistic, experimental and based on a knowledge-powered glocalism with a participatory approach, which could enable economic growth and employment while being based on an open source philosophy.

All these values are part of a new vision of the manufacturing perspective which involves not only specialists but the entire society.

Figure 27 - Carbon Dioxide Level (Parts per Million)
(Source: NASA)



rising at unprecedented levels (See Figure 27).[88]

High levels of CO2 cause reactions including global temperature rise, warming oceans, shrinking ice sheets, glacial retreat, decreased snow cover, sea level rise, declining Arctic Sea ice, extreme weather events, and ocean acidification.[89] These irreversible impacts have profound effects on our environment and will continue to present problems for generations to follow.

Highly industrialised nations are the largest emitters of greenhouse gases leading to environmental damage (See Figure 28).[90] Current levels of emission are historically high as the world becomes increasingly industrialised. Nations that emit large amounts of greenhouse gases and other harmful emissions will either need to tighten up regulations, having profound economic, social, and often political effects or face the consequences of environmental damage.

While industrialised nations do emit the largest amount of harmful emissions, a new case study has found that climate change has an adverse effect on manufacturing.[91] The study, which used data from 500,000 Chinese Manufacturing plants from 1998-2007, found that if no adaption by government or Nations that emit large amounts of greenhouse gases and other harmful emissions will either need to tighten up regulations, having profound economic, social, and often political effects or face the consequences of environmental damage. industry were to take place, manufacturing output will begin to decrease by 12% annually due to climate change effects.[92]

The issue of climate change is only one of many progressively detrimental environmental trends. Large amounts of waste, overconsumption and pollution also contribute to contaminating natural areas of the world and in turn jeopardises the health of the planet. The manufacturing community must begin to become environmentally conscious in order to create longevity for manufacturing innovation and to allow companies to sustainably grow.

Scarcity of Natural Resources

As the world becomes more industrialised, environmental challenges abound, including the worsening scarcity of natural resources.

Figure 28 -Top Ten Nations Who Emit Greenhouse Gases
(Source: World Resources Institute)

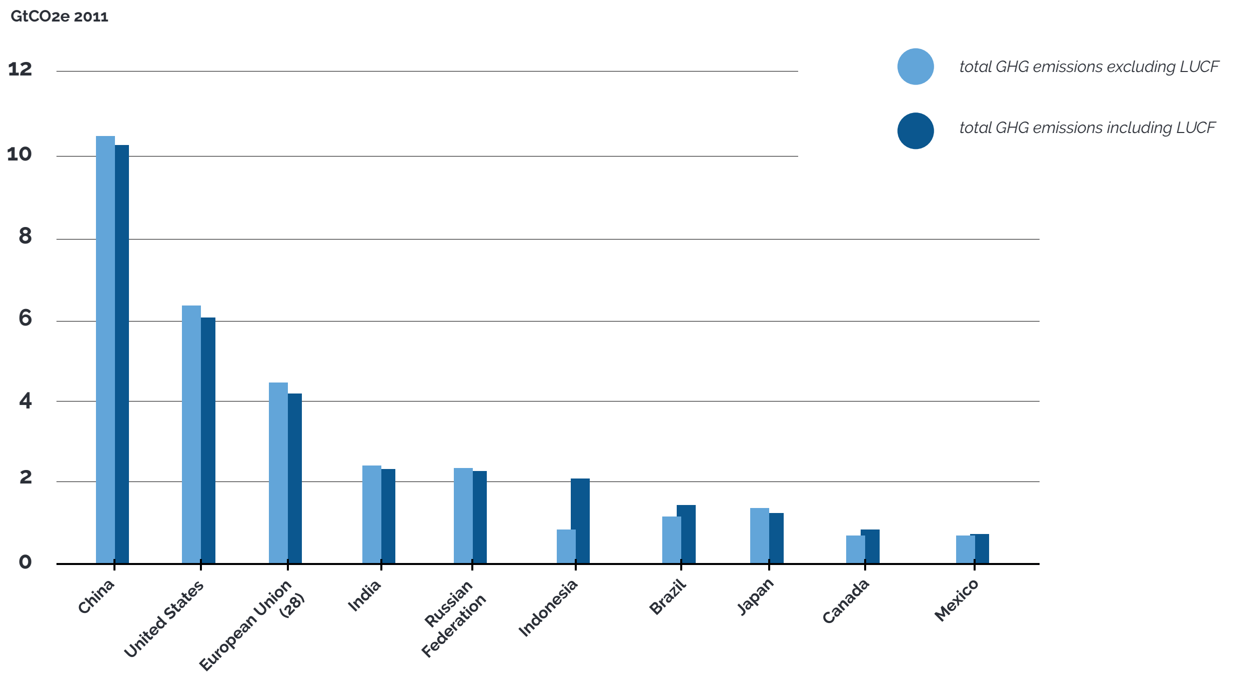
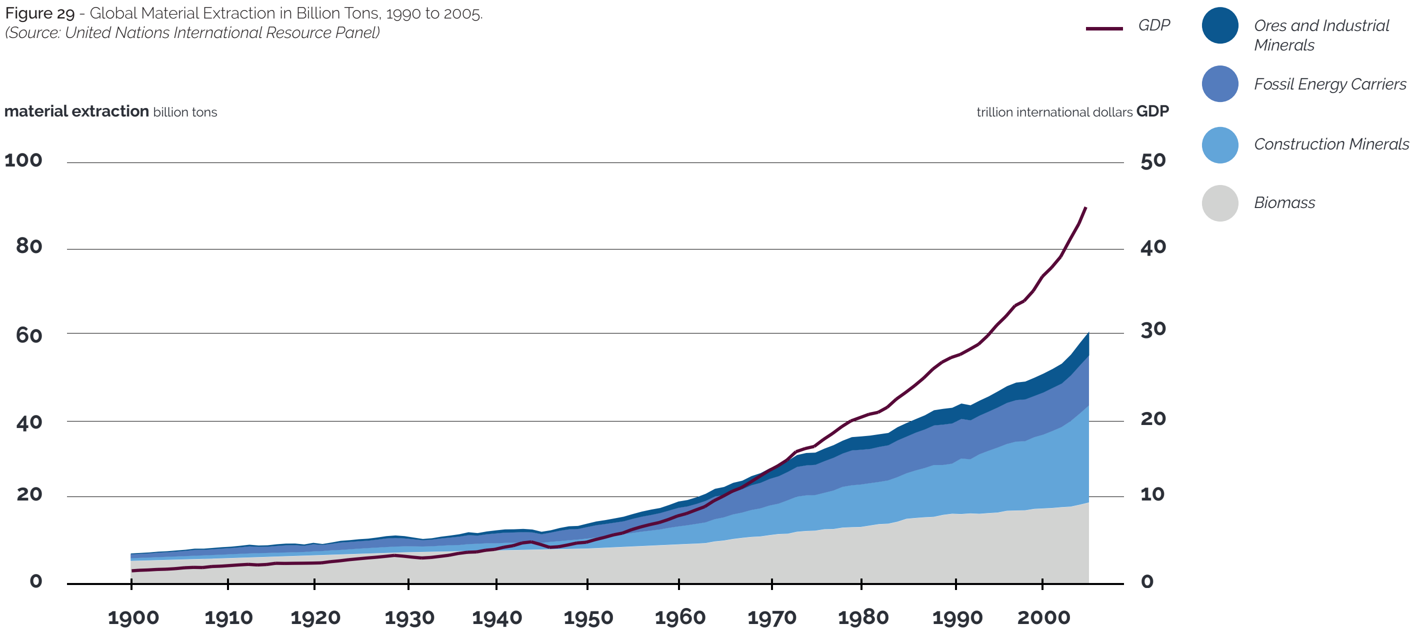


Figure 29 - Global Material Extraction in Billion Tons, 1990 to 2005.
(Source: United Nations International Resource Panel)



While scarcity of natural resources places environmental well-being in jeopardy, general industry and resource-related industries are also placed at risk from over-extraction. Global material extraction has been increasing exponentially along with global GDP despite the fact that many finite resources are being overexerted and face extreme scarcity in the near future (See Figure 29).[93]

The United Nations International Resource Panel predicts that if each person consumed resources at the same volume as current rates, resource extraction rates would almost triple to around 140 billion tonnes by 2050.[94] Although there are large reserves of many of these resources and immediate shortages are not of concern, their quantity is ultimately finite and future generations will be impacted by overuse and misuse.

Further, many countries engage in both exports and imports related to natural resource extraction at high rates. Large nations in developed or rapidly developing economies are heavily dependent on both exports and imports of natural resources making resource scarcity a threat to not only the environmental but economic health of the country.[95]

Over-extraction is not the only action putting a strain on resources. Climate change, coupled with the growing population, will have profound impacts on resources and global production. The global population is expected to demand 35% more food by 2030.[96] As incomes rise, food demands of populations include more products that have a high use of energy and water in the production processes. Even more, climate change could greatly reduce agricultural productivity around the world, particularly in Africa, which is estimated to lose one-third of productivity over the next sixty years.[97] The demand for resources, energy and water will have massively increased demands, making even the most basic of resources scarcer and the challenge of sustainable living even harder.

Businesses involved in energy and resource extraction are also struggling to balance two goals of providing enough energy to move the world's economy forward and spur economic growth while doing so in a clean and sustainable way. Though, there are positive signs regarding the future of resource and energy usage. Renewable energy is being utilised in tandem with scarce resources and use of renewable energy increased by 17% in 2017.[98] Additionally, better industrial practices and technological developments in resource extraction are becoming more efficient and effective yielding more product and less waste as well as increasing the overall amount of economically and technically accessible resources. Improved extraction and more opportunities will allow for better management of resources. While dealing with the delicate balance, world practices will need to shift and adjust along with the demand and use of scarce resources.

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO Global Cleantech Innovation Programme (GCIP)

Fostering Climate Technology Innovation, Entrepreneurship and Green Jobs in Start-Ups and SMEs

Alois Mhlanga
Chief of Climate Technology and Innovations Division, UNIDO
Sunyoung Suh
Cleantech Innovation Expert, UNIDO

Investment in climate and clean energy technologies in developing countries is expected to reach 6.4 trillion USD over the coming decade, with 1.6 trillion USD being accessible to small and medium-sized enterprises (SMEs). Typically, around 50% of the entire value stream of these technologies originates from major equipment proper. The rest is generated by balance of system components, smaller replacement parts, assembly, installation, operation and maintenance services and civil works. However, despite the enormous economic potential of climate and clean energy technologies, and the multilateral efforts to boost growth, these sectors have not achieved scale. To be able to fully participate in this newly emerging economic space, UNIDO supports developing countries to design appropriate strategies and targeted support measures to foster endogenous innovation, through the Global Cleantech Innovation Programme (GCIP).

GCIP supports partner countries to strengthen national ecosystems for clean technology innovation and entrepreneurship in start-ups and SMEs. A key component of the GCIP is the annual competition-based Accelerator, which systematically identifies promising innovations, and directly engages with them to support development of business plans that ensure market feasibility and commercial success while pursuing environmental sustainability. Equally important, the programme promotes the capacity building of national institutions and organisations, including government agencies, universities and Research and Development (R&D) centres, while trying to connect and strengthen existing national initiatives. It also works towards the introduction of policies and regulations which aim to create a market for clean technology innovations.

GCIP has been implemented in Armenia, India, Malaysia, Morocco, Pakistan, Thailand and Turkey. Ukraine is expected to join in 2019. Between 2011 and 2017, GCIP accelerated over 860 SMEs and start-ups globally. A survey of 14 randomly selected start-ups supported by GCIP shows that they created 329 new jobs, achieved annual revenues exceeding 23 million USD and managed to save 624 kilo tonnes of CO2 emissions. By addressing barriers that enterprises face in refining and commercialising their innovations, SMEs and start-ups in emerging economies can become a key driver of priority innovations. Further, their commercialisation can support the creation of new and green industries and jobs, as well as technologies and services that will drive the transition to a green economy.

GCIP Innovation Showcase: ***Bitsym***

GCIP Pakistan supported Bitsym from 2015 to 2017, an internet of things (IoT) solutions company that provides value chain innovations to small and large scale private and public organisations and direct end users. Its main product, Bitpredict, provides early information on potential equipment failures, permitting maintenance to be transformed from periodic reactive maintenance activity into one that can be planned and controlled for efficient management of valuable industrial equipment and assets saving valuable energy in the process.

Bitpredict uses Bitsym's extensive library of faults and prognostics data with custom sensor installations, where required. The approach combines Failure Mode Effects, Criticality Analysis and Data-driven approach with extensive data analysis including state of the art artificial intelligence deep learning and model building approaches.

Manufacturing Challenges

Manufacturing is considered a strategic industry for most national economies and as such subject to internal (e.g., number of jobs, contribution to GDP) and external (e.g., export/import ratio) attention. Manufacturing creates a multiplication effect that impacts several other economic sectors. The latest numbers quantify this effect in the US with an additional $1.89 USD being added to the economy for every $1 USD spent in manufacturing, while others report multiplication effects of up to $3.60 USD for every dollar of manufacturing output.[99] Furthermore, the manufacturing industry is responsible for three-quarters of all private sector research and development in the US. Therefore, it comes to no surprise that national governments try to fiercely protect and support their manufacturing industry though a variety of instruments. Those range from workforce development, research and development funding for new initiatives, to subsidies and even threats of new import tariffs or embargos.

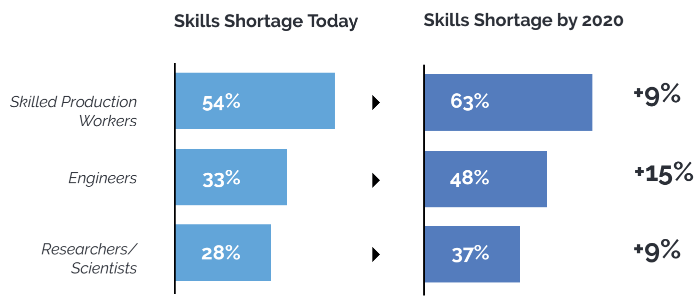
Manufacturing is and always has been at the forefront of technological advances and developments which ultimately shaped modern society as we know it today. With increasing connectivity and data-dependency that more and more defines the manufacturing industry, new challenges emerge that urgently need to be discussed and addressed before they cause problems on a global scale. History has shown the importance of the manufacturing sector regarding its impact on the global economy and stability. In the end, manufacturing directly and indirectly is an instrument that can lead to a more peaceful world or, on the other side, to a more confrontational one. Addressing the challenges depicted below early and committing the needed resources will help in pushing the lever to the former rather than the latter.

In the following, we will discuss today's major manufacturing challenges in the context of the previously presented societal megatrends. We have identified nine significant manufacturing challenges that will impact the manufacturing industry in the future. It should to be noted that these manufacturing challenges are highly interdependent and have to be seen in context with each other. An example of such interrelations is the trend towards mass customisation that, among others, drives the need for global-local agile supply networks.

Competences & Skills Gap for Advanced Manufacturing

The main reasons for a future competence and skills gap for advanced manufacturing are found in a reduced number of skilled workers due an aging population and lower birthrate in selected industrial countries, while the dawn of the *Fourth Industrial Revolution* and smart manufacturing brings forth new competence and skills requirements. In contrast to manufacturing of the past, most new manufacturing jobs will require a thorough understanding of technology beyond the immediate manipulation of materials or assembly tasks. Manufacturing systems will be more flexible and adaptable and with it, the manufacturing workforce such as operators and production planners. Repetitive manual labour will increasingly be automated; however, this will lead to new careers requiring advanced degrees and technical skills. This leads to the first major manufacturing challenge, the increasingly pressing competence and skills gap. In the US, it is projected that over 2 million manufacturing jobs will go unfilled due to the skills gap in the next decades.[100] It is predicted that by 2030 a global skilled labour shortage in manufacturing of 7.9 million unfilled positions will lead to an unrealised output of $607.14 billion USD.[101]

Figure 30 - Widening Skills Gap
(Source: The Manufacturing Institute)

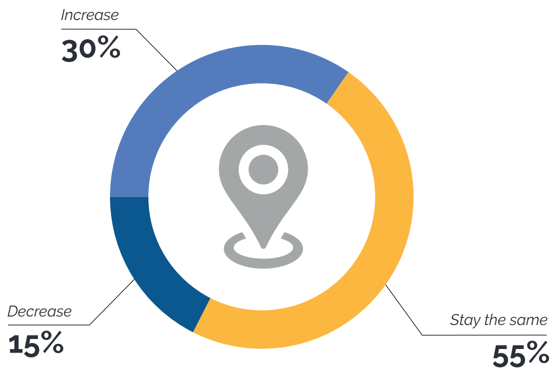


Most manufacturing executives are increasingly aware of this challenge yet struggle to find measures to address it.
Several trends have an impact on this development. First, the demographic change with a large number of *baby boomers* nearing retirement age is impacting the availability of qualified and experienced manufacturing professionals in several major industrialised countries such as Italy, Germany and Japan. Second, the change towards smart manufacturing requires a highly qualified workforce and new skillsets that are not unique to manufacturing,
Germany and Japan. Second, the change towards smart manufacturing requires a highly qualified workforce and new skillsets that are not unique to manufacturing, such as data analytics and composition of complex systems. Therefore, manufacturing companies compete with a number of other established and emerging industries for new workers from the same talent pool. The new generation of millennials who grew up in a digital world have ample opportunity to express themselves and manufacturing is often still perceived as dangerous, dirty and demanding – which, is not necessarily reflective of today's reality. Tech start-ups have a much more appealing reputation. On the other side, the available opportunities for low skilled workers are diminishing with more physical and cognitive automation of processes and tasks. Therefore, outsourcing and immigration of low skilled workers to reduce the imminent pressure for manufacturing companies is not addressing the key issue of an increasing shortage of a highly skilled manufacturing workforce. Most manufacturing companies are small and medium-sized and located in rural areas. As such, this skills and competence gap challenge is impacting them more than multi-national companies which can source talent globally, advertise the advantages of a manufacturing career and pay competitive salaries to compete with the tech companies. The notion of lifelong learning and continuous training for the existing workforce is becoming essential for manufacturing companies, service providers and education focused institutions alike. Close collaboration across all levels of professional education and training needs to be prioritised and innovative ways to develop flexible and customisable curricula that reflect the various challenges of on-the-job training.

Global-Local Agile Supply Networks

In the past, we saw large scale outsourcing of manufacturing operations to reduce cost and access qualified workforces. Today, we begin to see a trend towards a more geographical clustering of supply chains, re-shoring and a deeper integration of local manufacturing in the global supply chains. In contrast to previous decades, with globalisation setting the frame for outsourcing and global supply chains, today there is a trend to build supply chains focused on certain geographical areas. Three developing mega-supply chain clusters are located in Europe, North America and East Asia with centres of gravity in the US, Europe and China respectively. While there is more activity within the clusters, there is certainly exchange across these clusters. There are multiple reasons for this development that can be identified. Some are of technical nature, others are rooted in new policies, energy prices and, to an increasing extent, preference of consumers for locally manufactured products and a short delivery lead-time. In Figure 31, the results of a recent survey on the plans of manufacturers regarding reshoring their operations are presented.[102] A major driver of this re-shoring activity is smart and advanced manufacturing. Enabled by availability of data and better integration of digital systems this development is driven by the increasing demand from customers to either buy locally manufactured products or the pressure for customised products with short lead time.

Figure 31 - Reshoring Plans of Manufacturers Within the Next Three Years
In terms of "reshoring" or "nearshoring" manufacturing closer to markets, what is the trend in your company?
(Source: SCM World Globalisation Survey)



Two Challenges in the Data Value Chain

Olivier Verscheure
Executive Director, Swiss Data Science Center
Dimitris Kiritsis
Professor of ICT for Sustainable Manufacturing, EPFL

We live in the age of data, where everything that surrounds us is linked to a data source and many aspects of our lives are being more and more digitalised. It is alleged that the physical world around us has turned into raw data. To cope with this vast amount of data, Big data has emerged as an efficient and scalable means for raw data investigation.

Big data is widely described as having four main dimensions: volume, velocity, variety and veracity. Volume refers to the problem of dealing with very large datasets, which typically requires execution in a distributed cloud-based infrastructure. Velocity refers to dealing with real-time streaming data, such as video streams, where it may be impossible to store all data for later processing. Variety refers to dealing with different types of sources, different formats of the data, and large numbers of sources. Veracity applies to the trust and verifiability of raw data and insights resulting from an analysis.

Much of the work on big data has focused on volume and velocity, but the problems of variety and veracity are equally important in solving many real- world problems.

The Meaning of Data – Data Semantics

Under the lens of data heterogeneity, it can be argued that the fervent search for the meaning of data constitutes the Holy Grail of data integration. Let's illustrate its importance through an example.

A company organises an open corporate anniversary. Part of the event's goal is to disseminate all the recent products of the company as well as building greater investor confidence, and encouraging sales. After the end of the event, the company's director asks the sales department's director and the marketing department's director to prepare a short report of the number of customers that responded to the event. The sales department director replied with an estimation of 40 customers while the marketing department director replied with the astonishing number of 400. Their responses were not coherent at all, however, both were valid. In the mind-set of the sales department's director, a "customer" is a person who has already purchased a product. On the contrary, it is common in the marketing terminology to also account for a "customer", a "prospect"; a person who is likely to succeed as a potential customer.

Let's look at another example. Today myriads of data collected at every moment by various types of sensors and the trend is increasing with the availability of smaller, cheaper and more efficient sensors that can senses almost everything. Let's look more carefully at something that every human is doing very often: taking the temperature of our body with a simple thermometer. It is straightforward for everybody how to do it, how to read the value of temperature in degrees of Celsius or Fahrenheit and interpret the value shown on the thermometer. For example, if we see a value of 38.5 degrees of Celsius, we conclude that our fever is somehow high and we might need to call our medical doctor or take some medicine. Now let's think about this: what is the source of the data we read on the thermometer? The thermometer itself as many people reply to this question? But the thermometer itself is not able to create a heat or increase the temperature of our body. It is rather a phenomenon in our body that creates heat and increases its temperature which, in its turn, is captured by the thermometer if we apply it correctly and at the right point of our body. The above reflection can be done with any type of sensor that is used to capture the value of something we want to measure: temperature, vibration, acceleration, movement, etc. The real source of the captured data is not the sensor itself but a particular phenomenon of the object where the sensor is embedded on. The function of the sensor is to capture the value of a parameter allowing to assess the behaviour of the observed phenomenon.

In addition to the above, it should be noted that the collected data are always interpreted within the boundaries of a well-defined "context". The aforementioned examples illustrate the significance of identifying the meaning of data. As a solution to this challenge, a semantic data model tries to explicitly define what are things like "customer," "product," "credit limit," "net sales," and so forth. What the semantic modeler *must address is the context of the term - the data element - and how it relates to other data elements as present in the data sources. For example, is a customer an individual or a company? Must a customer have actually purchased a product, or can a customer also be someone who is in the market for a (the) product? What in some contexts might be called a "prospect" might be called a "customer" in others. Is a customer a wholesaler or is the end consumer the customer? Is the wholesaler's customer also called a customer? It is exactly this confusion that the semantic model strives to both reveal and resolve. In a general sense, semantics is the study of meanings of the message behind the words. The semantic modeler must drill down and capture the nuance of each perspective and must struggle to work with the business users to develop a naming convention or syntax that provides clarity. All perspectives are represented in the semantic model.*

Unsurprisingly, as noted previously, "information" is also often defined as "data in context". The number in the data is very abstract, and only when adding background, and transforming the number into a quantity with a specific meaning, the data is capable of turning into the valuable information. However, it is quite common that although we have an abundance of data, their information content is vague and unfortunately not so informative. The main reason is that although we pay a lot of attention on the process of gathering the data, we pay significantly less attention on standardizing their meaning, making explicit what these data describe. For instance, "credit limit" refers to the maximum amount of credit that a financial institution will extend to a debtor for a particular line of credit. However, this definition says little to us regarding the currency in which the credit limit is measured or its value type. All the information can be said that are lost in translation.

As a matter of fact, it is becoming more and more evident that the semantics of data are equally important to the raw data itself. Toward this direction, semantic technologies offer a complete toolset for simultaneously providing the raw data and their meaning, offering a unique way for establishing a contextual framework for data sources exposure. At the same time, they provide the tools needed for formally defining the terms and the relations that characterize a given domain, providing thus a standardized and machine-readable representational artifact (ontology) that can be used in a later step to account for the meaning of data. Finally, this explicit specification of the indented meaning of the data not only allows the meaning disambiguation, but it additionally enables the inference of new information which is not explicitly stored in the accessed data sources. As an example, let's imagine that a "credit limit" is assigned to a specific entity. Based on the definition of "credit limit", we can understand that this entity is a financial institution, although this may have not been explicitly stated.

The Trust in Data- Data Provenance

Today's high volume of generated data implies numerous corrupted, incomplete or "noisy" raw data. Professionals dealing with such material can legitimately doubt the results and analytics based on the information they are provided with: can it be trusted? Is it safe to (re)use? Data science techniques, tools and best practices therefore need to be put at work in order to clean, organize and ultimately extract insights from such vast amounts of (often chaotic) data.

There is however, a critical need for data science tools enabling trusted, verifiable analytics and results at all times.

These tools should enable data provenance materialization (for instance into a knowledge graph representation). This representation will serve as the basis for traceability of previous works, consequently providing enough information to enable a trusted collaboration.

Moreover, data lineage should be automatically recorded and seamlessly capture both the workflow within and across projects, allowing any derived data to be unambiguously traced back to the original raw data sources in a manner that is fully transparent. Because data lineage includes the code of intermediate data transforms or data analytics, it also enables reproducibility.

Conclusion

To conclude, it can be seen that the use of a semantic model is a fundamental step towards demystifying the meaning of data and can serve as a keystone for integrating heterogeneous data sources, boosting a smoother transition between the digital and the physical world. The semantic data model aims at providing an abstraction that defines how the instance data relate to the real world, in a unique and uniform way. To do so, the semantic modeler attempts to provide a unique specification of all the terms and relations that characterize a target domain, preventing in that way the data's information content to be lost in translation!

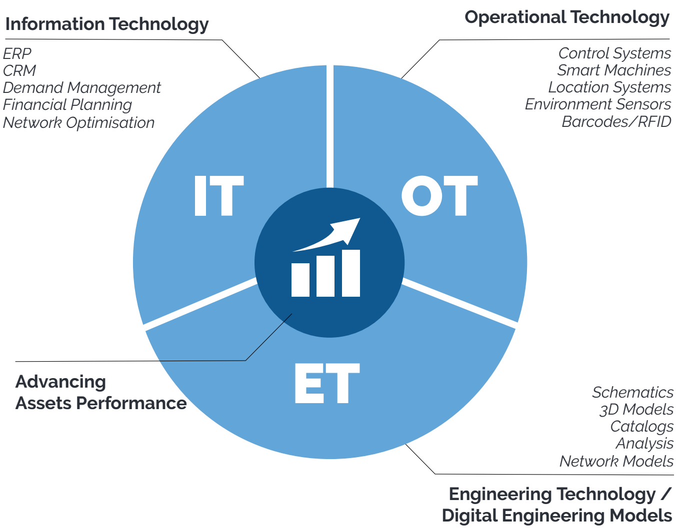
In the same manner, the use of a tool enabling reproducibility and traceability ensures the output of one analytics can become the input of another. Ultimately, projects gain in speed and efficiency and bring undeniable additional business benefits.

The resulting global-local agile supply networks face the challenge of establishing sustainable operations while facing increasing urbanisation for local production, while at the same time having to deal with the complexities of international trade policies as well as integrating variating cultural and structural conditions. Another effect of smart and advanced manufacturing is that the labour cost output ratio is becoming more competitive and thus the savings from producing in low (labour) cost environments is reduced while the increasing energy and fuel cost as well as import tariffs is increasing, making local production more attractive in a financial sense.

Integration of Information Technology (IT), Operational Technology (OT) and Engineering Technology (ET)

Much of the change in manufacturing is driven by the technological development regarding access, communication and analysis of large amounts of data. The different systems that ideally make manufacturing operations more effective and efficient are evolving rapidly, becoming more powerful and complex. With this development, a new manufacturing challenge emerges at the intersection of the different systems. In the new smart manufacturing systems, several components have to be integrated and work together as seamlessly as possible. This comes down to the Integration of Information Technology (IT), Operational Technology (OT) and Engineering Technology (ET).

Figure 32 - IT-OT-ET Integration [103]



In an increasingly digital world, connecting the data streams from new product development and design (ET), including CAD and PLM systems, to the production and resource planning (IT), such as ERP and MES, and real-time analysis of manufacturing data from the shop floor (OT), IoT sensor and machine tool data, is an essential requirement for success in the competitive marketplace. However, this integration is far from trivial and new platforms that promise to ease the integration have yet to prove their capabilities. The integration is not only hindered by different data formats and semantics but also differences between software providers, software versions and hardware installed. Even essentials such as forcing a common time clock across the operation is not an easy task to implement. Adding to the challenge is the agility of today's supply networks and flexible manufacturing systems where companies and business units are equipped with different systems and resources have to work together. However, in many larger but as well in some small and medium-sized corporations this presents an internal challenge that needs to be addressed in order to really profit from the developments and promise of Industry 4.0.

Another challenge is the availability of high-speed data infrastructure in itself, especially in some remote areas with manufacturing clusters. We established that manufacturing today depends on reliable and fast connectivity more and more and not having access can be a major competitive disadvantage. New, predominantly wireless options such as the 5G standard are being developed and deployed. This is projected to boost the ongoing development of the digitisation of manufacturing even further, reducing the expensive development of physical infrastructure to some extent. However, integration challenges of legacy systems similar to the previously described IT/OT integration persist and have to be actively addressed in order to leverage this new opportunity to its full potential.

Scarcity of Natural Resources and Reduction of Energy Consumption

The purpose of manufacturing, in general, is to add value by transforming raw materials into a final product by a sequence of manufacturing processes. While the manufacturing processes vary from product to product, they all have in com-

Zero Defect Manufacturing

Roberdo Perez
Head of Innovation, Digital Transformation, GF Machining Solutions

In recent years, companies have been producing new products faster than ever for two main reasons: to increase profits and to respond to an increased demand from their customers. Moreover, with the rise of product customisation industries have shifted to manufacturing methods based on lean practices and customer demands. Therefore, it requires more adaptability from firms to match their clients increasing expectations. It also becomes much more challenging to apply systematic methodologies for monitoring and preventing the occurrence of defects within manufacturing shop floors due to the increased complexity of both the products and the production systems. Further, making smaller batches of customised products results in an increased defective products rate. Taking these trends into consideration, new and more sophisticated manufacturing strategies and tools are needed.

One of these strategies is called Zero Defect Manufacturing (ZDM). This strategy has a goal to decrease and mitigate failures within manufacturing processes and "to do things right in the first time." In other words, to eliminate defective parts during production.

Zero Defect Manufacturing can be implemented through two different approaches. The product oriented ZDM and the process/machinery oriented ZDM. The difference is that a product oriented ZDM studies the defects on actual parts and tries to find a solution whereas the process/machine oriented ZDM studies the defects of the process and associated manufacturing equipment and based on information can evaluate if the produced products are good. This is contained within the predictive maintenance concept.

ZDM consists of four strategies: detect, repair, predict and prevent. The four strategies are interconnected as follows and apply to both the product or process/machine-oriented approaches. If a defect is detected, then it can be repaired and the data gathered by the defect detection module is populated into specifically designed algorithms that will predict when a defect may occur and therefore will be able to prevent it. Here the phrase mentioned earlier, "to do things right in the first time" becomes relevant.

There are many reasons why the ZDM concept is attractive for companies. First, it can considerably reduce costs of the company's resources related to the treatment of defective products. Beyond that, the overall production chain can be continuously improved. This approach can also increase safety and customer satisfaction, which may strengthen customer loyalty and increase financial benefits for the company.

Now the question is: if this strategy exists, why has it not been implemented for many years? The answer is that there were many technological limitations hindering ZDM. The ZDM concept requires a huge amount of "standardised" data for algorithms such as machine or deep learning in order to be implemented or work properly. Even now, there are numerous companies that have not yet adopted this digitisation of their production lines as is necessary for Industry 4.0 implementation. However, the landscape has now changed with seamless connectivity, computer power, data storage and sensor prices dropping significantly along with the new Machine2Machine (M2M) communication frameworks that make the concept of ZDM possible. ZDM will be the new standard for companies moving towards more eco-friendly, efficient and zero defects production lines.

mon that they require energy to operate and raw materials as an input.

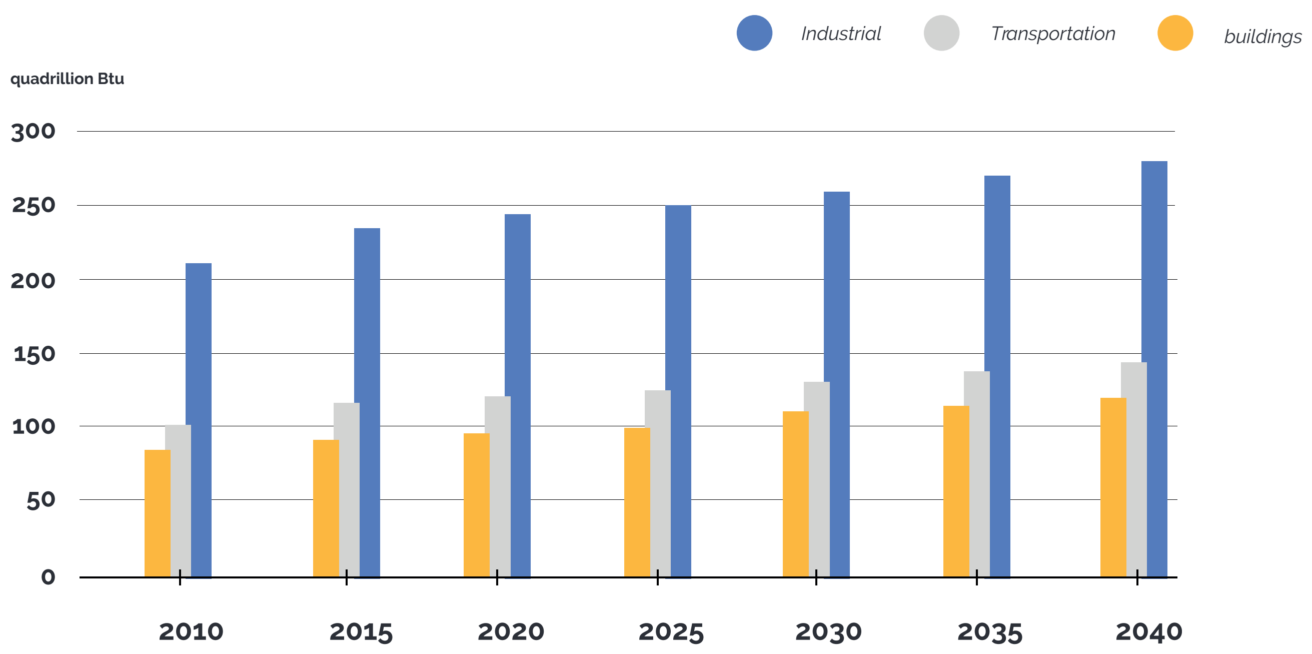
The form of energy, ranging from mechanical to optical, varies with new advanced manufacturing processes like Electron Beam Melting (EBM) or Direct Metal Laser Melting (DMLM) require significant amounts of energy to operate. Especially in the early stages of a manufacturing process chain, where the raw material is processed, some transformation processes are very energy intensive, such as copper or alumna smelters. The energy intensity of such processes traditionally leads to an accumulation of processing facilities in close proximity to abundant and low-cost energy resources. An example is Iceland, with lots or thermal renewable energy, and Brazil, with extensive hydropower-based energy. Shipping the raw materials, such as bauxite, to these locations and the processed intermediate product, such as aluminium slabs, back again require energy for the logistics. Together with the trend to keep value adding operations within close proximity of consumers, new facilities have emerged with new sources of low cost energy, such as natural gas, in North America. Overall, given the scarcity of certain natural resources and the need to reduce energy consumption with regard to climate change, manufacturing faces increased scrutiny to reduce the energy footprint and find innovative ways to operate more sustainably.

While energy scarcity is still a major concern, in some cases technological developments increased the (economically and technically) accessible resources and thus continuously reduce their scarcity. It is projected that this development will continue to some extent, leveraging the imminent threat of running out.[104]

While for some processes there are physical constraints that limit the possibility to reduce the energy footprint, utilising improved data-driven process control can lead to a reduction in overall energy consumption by reducing the number of scrap parts and quality issues in the process. Furthermore, producing a larger percentage of the components of a product in close proximity to the customer reduces the energy impact of the global supply chain.

The input raw materials of the manufacturing process are traditionally clustered in metals, polymers and ceramics. While the majority of these raw materials are available in relative abundance, certain specialty materials, such as rare earth minerals, are facing rapidly increasing demands and at the same time reduced availability. As those speciality raw materials are utilised in many key technologies such as tablets or small-scale actuators, or in applications like lightweight alloys, their scarcity is amplified beyond the means of their use by volume.

Figure 33 - World Energy Consumption by End-Use Sector
(Source: US Energy Information Administration)



New innovative ways of recycling and reuse, as well as the development of new applications to substitute scarce raw materials, e.g., composites, are required to alleviate the impact of this challenge.

Mass Personalisation

Before the first industrial revolution, practically all goods were craft product, more or less personalised as "one of a kind." Following the second industrial revolution, mass production lead to an abundance of the same product with the benefits of economies of scale. Most remember the famous quote from Henry Ford in which he states that customers can have his model T in any colour they desire- as long as it is black. Today, customers are demanding customised and increasingly personalised products that reflect their unique requirements while at the same time expecting a competitive price that is only possible through economies of scale. This is different from how manufacturing operated in the past. Today, in some sectors we already experienced this phenomenon in the form of mass customisation, where customers can customise their product by choosing from a set of options, such as colour and trim of a new car, to fit their demands better. However, we are rapidly moving towards truly personalised product design where products are specifically built for one unique customer according to her or his individual requirements. In this case, the product and experience is one of a kind and unique to this customer. This must be achieved while still ensuring the efficiency of mass production and therefore is commonly referred to as mass personalisation.

The theoretical concept behind mass personalisation is not new, however, with the technological developments of the *fourth industrial revolution* such as IoT, the objective of producing batch size 1 at mass production cost is considered to be achievable and in the realm of possibility for the first time. The ability to integrate the individual customers' needs and requirements early during the design and manufacturing process as well as to collect and analyse large amounts of individual usage data creates both a challenge and opportunity. The ideal depth of integration of the customer in the product creation process has yet to be understood and is most likely specific to customer, product and company. Another driver of mass personalisation is again the demographic change, demanding for personalised yet competitively manufactured (bio-) medical products. With maturing technologies like metal additive manufacturing, a unique, personalised artificial hip can theoretically be produced locally to the exact specifications, which might be based on personal data collected through material integrated sensors of the patient or customer. At the same time, the processes and policies for accreditation and warranties of such individual solutions have yet to be determined.

Hybrid and Smart Materials

New materials have influenced societies for thousands of years with whole eras, such as the bronze age, carrying the namesake of a material. While there is always a gradual development improving materials and processing, we are in the midst of another materials' related revolution. This revolution is actually two-fold: new materials and materials integrated intelligence. The former describes new materials that provide a significant step forward in the possibilities they offer for products in terms of materials properties such as strength and weight ratios and the latter describe the possibility to have materials act as information collecting devices themselves.

New materials include graphene, which is gradually emerging from a theoretical concept to a material that can be used in manufacturing applications and the field of composite materials. Particularly, composite materials are presenting a challenge for designers and manufacturing engineers because they do not follow the same principles as traditional materials like metals. While metals generally experience the same properties in all directions, composites require the design and manufacturing engineer to carefully consider the orientation of the fibres in the matrix materials in order to use their full potential and to avoid problems during the use phase. Furthermore, additional challenges emerge when it comes to end-of-life of these new materials as their recyclability is not yet well developed.

Smart materials are another novel topic that is developing quickly and brings together formerly unrelated areas like sensor technologies, signal and data processing, networks and communication as well as energy supply. Traditionally, external sensors have been used to monitor materials' behaviour. Sometimes, the sensors have been integrated in the material on a surface or near surface level. However, first attempts are now underway that aim for volumetric integration of sensors in the material itself and ultimately, the use of intrinsic material properties as sensors in themselves. Once this is achieved, this opens up a tremendous opportunity to gather data and information for all kinds of new applications and services.

Both the novel materials that are now available and in use, as well as the system integrated intelligence that is the basis for smart materials, creates opportunity for designers and engineers to create better, more efficient and more personalised products. However, the barriers of understanding how to best utilise and integrate these new materials in products in a safe and value adding way need to be reduced.

Data-Driven Manufacturing

The previous six manufacturing challenges all had the increasing interconnectivity and availability of data in the new reality of smart manufacturing at their core. Having access to and being able to utilise large amounts of data opens up many significant opportunities across all manufacturing and leadership functions in an enterprise. An indication on how valuable resource manufacturing data is considered already is the tendency to specify access, usage and ownership of (manufacturing) data in new contracts.

For the first time, large amounts of data are now not only available for the majority of manufacturers, but also the means of analysing them in an efficient and effective way. This allows for real time decision support from the shop floor to the C-level. Decisions are based on highly-granular, high-quality data in real time in an increasingly automated fashion utilising advanced machine learning algorithms and Artificial Intelligence (AI). However, this utopia of fully automated data-driven decision making is not trivial to achieve and even major global technology companies struggle to exploit the full potential today.

There are several challenges that have to be overcome in order to make this utopia a reality for the majority of manufacturers. Besides the challenges already described in the other sections of this chapter, there are specific data focused ones that deserve attention: with the abundance of data and low-cost sensors comes the challenge of ensuring the quality of data in a noisy environment such as manufacturing. While there are algorithms available that allow automated pre-processing of large amounts of data, in manufacturing, the non-stationary environment and rapidly changing conditions often require an experienced data analyst to ensure the data quality. If this step is not performed correctly, important decisions can be based on low quality or even corrupted data, which is often worse than having no data at all.

On the other hand, again emphasising the non-stationary environment manufacturing is set in, the changing conditions present a challenge for data-driven models as they are based on historic data. Additionally, in manufacturing, the data sets tend to be naturally unbalanced. This implies that there are significantly more examples of one class than the other, e.g., products of acceptable quality and non-acceptable quality. While this is necessary for a company to remain competitive, it presents a challenge for training an accurate prediction model due to the overrepresentation of one class. Therefore, new, manufacturing focused algorithms need to be developed that actively address these challenges.

There are several more challenges inherited with the shift towards data-driven manufacturing, including the on-boarding and mind-set shift of the workers, form operator to senior executive. However, we want to emphasise one more that increasingly emerges in conversations with industry: When does manufacturing process data pass its useful life and can be deleted? Some processes produce terabytes of data every minute and hosting, analysing and maintaining the data infrastructure requires increasing resources and adds to the hidden cost of machine learning.

Data Security and Data Authority

The trend of more critical and valuable data and information being collected and available in digital form and the awareness of the value of such data and information has led to an increasing emphasis on data security and data authority.

There are several aspects in this area that need to be distinguished. On the one end, there are criminal acts of attempting to access and/or manipulate data and information, such as

Models for Manufacturing

Fernando Mas
Senior Expert, Virtual Product Engineering, Airbus Defence & Space INTERNAL

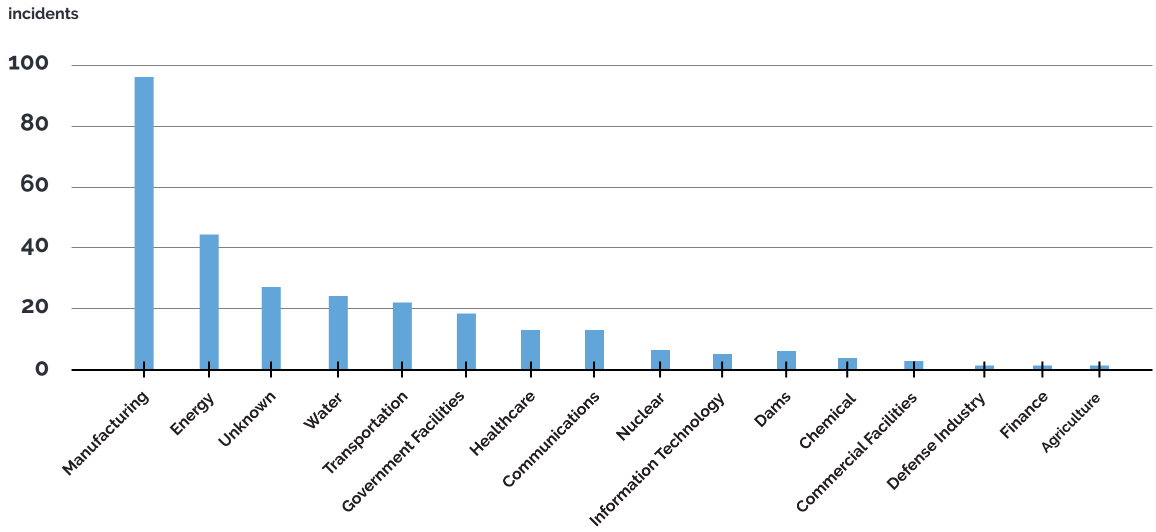
Aerospace assembly lines for major components or Final Assembly Lines (FAL) for aircrafts are huge industrial installations that involve complex assembly processes, sophisticated jigs and tools, machines and industrial means and skilled human resources. According to the specific features of an aeronautical assembly line, the number of assembly stations relates to technological criteria rather than to a calculation aiming to minimise the total number of stations. During the conceptual phase, it is critical to co-design and one of the best tools is to have a common deliverable between functional and industrial design.

The configuration management and product structure in Airbus can be simplified by 3 levels of the aircraft structure: the upper level, the configuration level and the lower level. The upper part of the aircraft structure is invariant, independent of the configuration and therefore common to every aircraft. The lower part of the aircraft structure depends on the configuration. The configuration level is invariant and defines the configuration layer where all the components and assembly drawings, Design Solutions (DS), are common to every aircraft. Every assembly drawing defined, Design Solution (DS), requires a Manufacturing Solution (MS). Functional and industrial design work concurrently, both developing each DS and MS. This process allows the "As Designed" and the "As Planned" to share the same components. This level, where objects have a correspondence between DS and MS, is the configuration level. The common deliverable mention before is the pair DS-MS.

Models for Manufacturing (MfM) is a new approach to apply Model Based Systems Engineering (MBSE) concepts to manufacturing. This aims to support collaborative engineering, early industrial definition and intensive use of simulation. An approach for modelling manufacturing systems in the aerospace industry, and in particular for Final Assembly Lines (FAL), has been proposed by Airbus research teams during the last years. Functional and data models have been published and deployed using data structures available from commercial PLM systems.

The commercial data structures are proprietary, poorly documented and suffer changes between versions. To avoid this and to have the ability to set up better models, a new architecture based on 3-Layers Model (3LM) has been defined: a Data layer, an Ontology layer and a Service layer. The Ontology layer is the core of the 3LM. The Ontology layer defines: Scope model, Data model, Behavior model and Semantic model, to further instance information from existing databases. The Scope model is mandatory because manufacturing is a large and wide part of the artifact lifecycle and Data model can cover several different uses across it. In parallel, software architecture to support the methodology is being developed using Free and Open Source Software (FOSS) tools. In particular a PLM tool, ARAS Innovator is the core of the system. Other tools like IDEF0 and CMap are used by the authors as modelling tools.

Figure 34 - Cyber Security Incident by Sector
(Source: US Department of Homeland Security)



hacking into a manufacturing company's data base. These criminal intruders aim to steal valuable information as a form of corporate espionage or, in case of manufacturing companies working on military contracts or critical infrastructure, national security. With manufacturing operations being increasingly digitalised and connected, stealing is only one possible threat that can occur. Another option is that the intruder manipulates the data and information in a malicious way with the intent to either damage the manufacturing machines, e.g., by changing operating parameters, or the end user of the manufactured product by changing, e.g., the load bearing structure within the CAD models. In the latter case, the product will not perform in the intended way and can cause serious harm to the user. Therefore, manufacturing is increasingly in the spotlight for cyber threats. The US Department of Homeland Security collects reports of cyber security incidents for critical infrastructure and the manufacturing sector reported the most incidents in 2015 (See Figure 34).[105]

Conversely, the access to and dependency on data opens up the possibility for misuse within the operation itself. This is a major challenge in the age of smart manufacturing and connected supply chains. This challenge is manifold as it is relevant on several levels. On a technical level, the communication and security protocols of all connected devices in use have to be monitored and ensured. Data sharing across partners within a supply chain, that might be located in different countries with different policies and rules and across different systems adds another layer of complexity. These variating local regulations can create significant hurdles that can impact the whole operation of a global manufacturing supply chain. Companies with operations in different countries, e.g., in the EU, the US and China, may have to adhere to several different, often conflicting regulations. This might prevent them from utilising their data to the full possible extent, when they are required to store their data within the EU for their facilities in the EU, while the US requires them to follow their data transparency rules.

Managing data as the most important resource in a manufacturing company presents a significant challenge that needs to consider potential positive and negative impacts of sharing and granting access with regard to the dynamics of a non-stationary global manufacturing environment. This challenge is likely to persist as data and informational value increase with its possible uses, such as sharing with trusted partners. However, it also can cause serious harm if shared with or accessed by the wrong entity, such as a direct competitor.

The Paradox of SMEs' Digital Divide

Many of the previously discussed manufacturing challenges are relevant for both SMEs and large multi-national companies. However, there are certain aspects of the recent paradigm shift in the manufacturing industry that present specific challenges for SMEs. New technologies are readily available and at the same time, their cost is decreasing significantly. On the other side, the expertise required to understand them and their potential, as well as the associated cost to adopt them, especially the organisational cost, is not trivial. Large multi-national companies internally have the resources, skills and knowledge to manage this digital transformation.

Therefore, they are constantly on the edge of the innovation frontier. On the contrary, most of the time SMEs are unaware of the availability of new technologies, let alone the opportunity associated with it.

In a recent study, it was found that the majority of SMEs have heard of developments such as Industry 4.0, smart manufacturing, IoT and CPS and understands that their relevance to their business is significant.[106] However, only a fraction of them are actively working on implementing these technologies, stating lack of resources, knowledge, skills, and expertise – generally being not prepared - as the main barrier.[107]

This phenomenon, known in society as digital divide, risks to be true also for the business environment with the consequence of making SMEs even less competitive than large-sized companies. The paradox is that a technological innovation, which should be a competitive advantage, becomes a threat for the survival of SMEs.

Adding to this challenge is that many new supporting tools intended to support companies in their transition towards Industry 4.0 are not reflecting the requirements and needs of SMEs sufficiently. SMEs are being tied up in their daily business struggles and cannot demand the support that they need.

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO Programme for Country Partnership for Ethiopia – PCP Ethiopia

Dejene Tezera
Director, Department of Agribusiness, UNIDO
Mattias Larsen
Programme Coordinator Specialist, Agro-Industries Technology Division, UNIDO

UNIDO has developed a new programmatic service to advance inclusive and sustainable industrial development (ISID) in Member States, the Programme for Country Partnership (PCP). PCPs are currently being piloted in six countries: Ethiopia, Senegal, Peru, Cambodia, Kyrgyzstan and Morocco. The PCP brings together actors in a multi-stakeholder platform to coordinate and optimise the contribution of each. The objective of the partnership is to accelerate the implementation and deepen the impact of the governments' industrial development agenda.

PCPs are tailored to country needs and each government maintains leadership through a national coordination mechanism. The PCP is aligned with the national industrialisation strategy, priorities and development plans. It creates synergies through partnership interventions; for example, through cooperation with development finance institutions, UN entities, private sector and other development partners. The PCP leverages large-scale public and private investment for industry, infrastructure and innovation. It is anchored in a strong analytical framework and focuses on priority sectors essential to the government's industrial development strategy. A results-based management system underpins the analysis of programme-level results.

Two examples of a very tangible intervention by UNIDO through the PCP, originating from priority initiatives of the Government of Ethiopia, are the development of integrated agro-industrial parks (IAIPs) and associated rural transformation centres (RTCs) along with the development of the Modjo Leather City (MLC) industrial district.

An IAIP is a geographical cluster of independent firms grouped together to gain economies of scale and positive externalities by sharing infrastructure and taking advantage of opportunities for bulk purchasing and selling, training courses and extension services. Four pilot IAIPs are currently being established in the Amhara, Tigray, Oromia and Southern Nations, Nationalities and Peoples' (SNNP) regions respectively. A total of 17 IAIPs are being planned and will be located in identified agro-industrial growth corridors. The Government of Ethiopia has invested $300 million USD towards the development of infrastructure for IAIPs and a further investment of $500 million USD is expected from the private sector.

The Ethiopian leather industry enjoys significant comparative advantages as Ethiopia has one of the world's largest livestock populations. Improper planning during the establishment of the tanneries in Ethiopia led to difficulties in monitoring and mitigating pollution produced by the tanning industry. The MLC will be an industrial park which presents an opportunity to set-up an environmentally friendly leather tanning district, driven by a network of tanneries and a common effluent treatment plant. The European Investment Bank (EIB) intends to fund up to 50 percent of the loan required for MLC construction. UNIDO will further support MLC development through a new large-scale programme approved for funding by the EU entitled "Leather Initiative for Sustainable Employment Creation."

The PCP allows UNIDO to scale up its technical assistance from fragmented smaller-scale operations to concerted operations in large programmes. UNIDO will leverage grant money to mobilise larger resources, for the IAIPs and the MLC in Ethiopia for example, through conceptualisation by undertaking feasibility studies, by developing management systems and producing environmental and social impact analyses that are then used to leverage additional large-scale funding.

Future-Oriented Manufacturing

In the next twenty to thirty years, manufacturing will look very different and virtually unrecognisable compared to today. Successful companies will be able to rapidly adapt their physical and intellectual infrastructures to exploit changes in technology as manufacturing becomes faster and more responsive to changing global markets and closer to customers. Current trends will push the factories of the future, products and processes to be extremely sustainable, with built-in reuse, remanufacturing and recycling for products reaching the end of their useful lives.[108] In transforming the current landscape of the manufacturing industry, there are a number of innovative enabling technologies such as 3D printing, IoT, AI, cloud technologies, data analytics, visual technologies including AR and VR for factory workers, cognitive computing, digitalisation from design to production, advanced robotics and blockchain among many others. Collectively, all these technologies will impact manufacturing in two main dimensions: the way companies are working internally, and the way they interact within their external ecosystems and value chains. All things considered, the factories of the future will be a very different place than it is today as the industry renews itself for the digital age.[109]

In this context, a new industrial vision built by multi-directional focus to reinforce sustainable growth and enhance global societal prosperity is needed. In this respect, six disruptive trends for the future of manufacturing (See Figure 35) are a source of great opportunity for delivering solutions of excellence:

1. Transforming conventional computing into a cognitive system in order to pave the way towards the large influx of data and the complexity of analytics, the new era of **Cognitive Manufacturing**, at the intersection of hyper-connectivity and advanced artificial intelligence, will revolutionise the factories of the future in four core dimensions: hyper-connected intelligent machines; AI-driven cognitive operations; smart optimisation of resources; and collaborative manufacturing as a service in the cloud.

2. Hyper-Personalised Manufacturing will take personalisation to the next level by analysing information in the public domain to create unique, precise, and personalised offerings of products and services that are highly tailored to the requirements and needs of consumers.

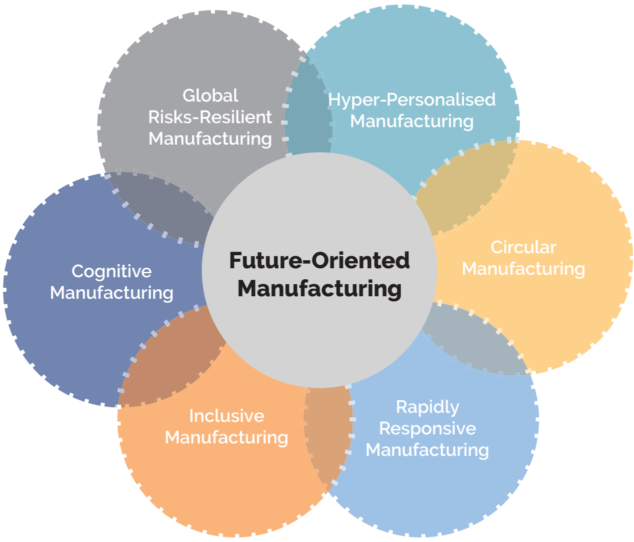
3. Future-Oriented Global Risks-Resilient Manufacturing systems will be able to recover their functions in the realities of global risks via strategic decision making and business model upgrades considering the hyper-connectedness of value creation chains.

4. Circular Manufacturing will perpetuate reuse of resources in the form of materials and energy via ingenious design of socio-technical systems and effective use of information to deal with challenges such as resource scarcity, waste generation, and pollution by managing the whole lifecycle of a manufactured product.

5. Inclusive Manufacturing will empower individuals of any gender and age from all social, economic and cultural strata boosted by the people-, environment- and technology-oriented innovations in order to ensure equity and well-being of every societal unit.

6. As a predictive, agile, flexible and lean model of production, **Rapidly Responsive Manufacturing** will react quickly to and take advantage of changes in market conditions, customer preferences, manufacturing conditions and social demands

Figure 35 - Six Disruptive Trends for the Future of Manufacturing
(Source: World Manufacturing Forum)



Cognitive Manufacturing

At the intersection of hyper-connectivity and advanced artificial intelligence in the factories of the future, *Cognitive Manufacturing* holds the promise of transforming industry by endowing production systems with perceptive and decisive capabilities enabling autonomous operations based on embedded cognitive reasoning in which the intelligence and reasoning are retained by humans and backed by core technologies of Industrial Internet of Things, big data analytics, mobility, collaboration, robotics, augmented reality and cognitive computing.

Built on the foundations of the IIoT and utilising data analytics combined with cognitive technology, the emerging field of *Cognitive Manufacturing* is characterised by the vision and capacity to perceive changes in the production process and know how to respond to these dynamic variations with minimal human intervention. It does this by proposing improvements in processes and operations while suggesting alternatives to reduce cost and environmental impacts. The new face of manufacturing is defined by a confluence of long-standing trends in manufacturing and information technologies, including universal connectivity, cloud computing delivery models, smart digital manufacturing machines, and plant automation, all of which together bring about a digital revolution in manufacturing.

Hence, using cognitive intelligence to activate the next generation of production successes, *Cognitive Manufacturing* (See Figure 36) holds the promise of transforming industry in four focused ways:[110]

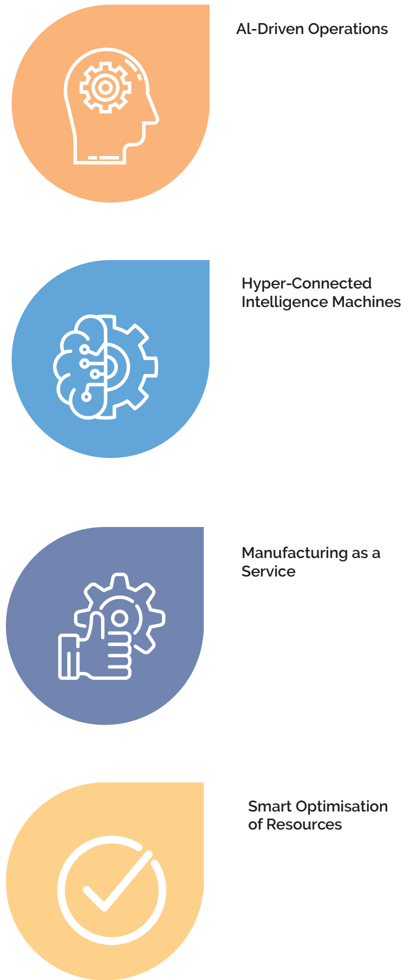
- **Hyper-Connected Intelligent Machines:** *Cognitive Manufacturing* will lead to the creation of hyper-connected manufacturing ecosystems with intelligent machines communicating to each other, promising better production productivity, deeper insights into what customers want, more reliable products and new revenue streams. Backed by AI utilising connected sensors, analytics, and cognitive capabilities to sense, communicate and self-diagnose issues and a wealth of insights from raw data, these machines will configure production processes and make modifications in real-time to optimise operations.

- **AI-Driven Cognitive Operations:** Integrating millions of data points into a source that discovers patterns and answers questions across the plant including users, equipment, locations and streaming sensor data, AI-driven cognitive computing represents an emerging technology which increases productivity, yield and quality while continuously learning to improve manufacturing processes and outcomes.

- **Smart Optimisation of Resources:** Combining various forms of data from individuals, location, usage, and expertise with cognitive insights, cognitive manufacturing optimises and enhances resources such as labour, workforce, and energy while creating new interactions between humans and machines. Thus, a cognitive manufacturing system has the ability to reason and form hypotheses, make considered arguments, and prioritise recommendations, supporting the future workforce for better decision making.

- **Collaborative Manufacturing as a Service in the Cloud:**[111] Integrating digital manufacturing with the IoT and cloud to bring about new benefits enabled by cognitive manufacturing, the goal of this new concept, also known *as Manufacturing as a Service* is to build a cloud-based platform that will connect small and large factories in a cloud and offer tenants all the advantages of the entire infrastructure. Manufacturing as a service is therefore the shared use of a networked manufacturing infrastructure to produce goods. In other words, manufacturers use the internet to share manufacturing equipment in order to reduce costs and make better products, relying on cloud-networked manufacturing. As network bandwidth becomes more accessible and affordable, manufacturing capabilities for machines, plants, and enterprises are interconnecting to form a global grid of manufacturing resources that can be consumed as a service through their virtualised interfaces on the cloud.

Figure 36 - Four Focused ways of Cognitive Manufacturing for Transforming industry
(Source: World Manufacturing Forum)



Hyper-Personalised Manufacturing

Powered by data via access to large amounts of information across the value chain, *Hyper-Personalised Manufacturing* takes personalisation to the next level by analysing information in the public domain to create unique, precise, and personalised offerings of products and services that are highly tailored to the requirements and needs of consumers, evolving into a customer-centric business environment capable of developing customised products for both local and global markets to build greater trust with their customers.

There will be an increasing demand for personalised products and services over the next years, with the related need to produce an increasingly heterogeneous mix of products in small or large volumes. From the design and production perspective, manufacturers will need to respond very quickly to a much wider variety of product specifications, and further develop their innovation and technological capabilities to cope with increasing demand and competition.[112] In this context, emerging technologies such as 3D printing that can deliver individualised products and services enabling the digitalisation of manufacturing, will support companies in responding to greater demands for personalisation.

Rapid advancement in technology and automation has made the manufacturing smart along with creating a personalised customer-driven business scenario. Companies have an interest, more than ever before, in accessing more and more information to create personalised customer experiences. The personalised information assists in making informed decisions and thereby satisfying the customer needs and adapts to the customers' delight.[113] Toward this purpose, hyper-personalisation has pushed the industries to evolve to a customer-centric business environment and establish manufacturing closer to the customer which results in the inclusion of local-social factors in prominence. For example, automotive companies are using the philosophy *build where they use*, bringing in new products using the local workforce. Such a cultural integration presents another dimension for understanding.[114]

New disruptive technologies like big data and predictive analytics, cloud computing, the internet of things, design thinking, social media and 3D printing are transforming manufacturing. Companies today have access to large amounts of information from across the value chain and can utilise this to create unique, precise, personalised offerings. The positive side of these new disruptive technologies supporting the hyper-personalisation trend is their ability to bring manufacturing as close to the customer as possible, therefore allowing value addition in the same region, county, city or community as the consumer. Hence, in hyper-personalised environments, consumption facilitates production or part of the production in the same locality, and allows for inclusive growth. Hyper-personalisation therefore commands a certain closeness with, and to, the customer.

While the *Fourth Industrial Revolution* creates asset intensive smart factories, it is local, asset-light hyper-personalised manufacturing and assembly that will spur inclusive growth. In the future, successful companies will be those that are able to deepen customer intimacy, and respond to their customers' requirements immediately. In that vein, hyper-personalisation allows the Industry *Fourth Industrial Revolution* to listen to consumers by analysing information in the public domain and then create products that are highly tailored to the requirements and needs of consumers, like the case of a garment manufacturer who analyses the likes and dislikes of a particular group on social media to determine what sort of designs will work for that group in the future. Through Industry 4.0, manufacturers need to understand that operational excellence reaches far beyond product production now more than ever before, thanks to the demands of discerning consumers for hyper-personalised experiences.

Advances in AI and software intelligence are enabling companies to take personalisation to the next level by making products and services that are highly relevant to individual consumers. This is important because personalisation sells.[115] According to a recent survey from Accenture, 20% of consumers are willing to pay a 20% premium for personalised products or services, and 83% of consumers in both the US and UK are willing to have trusted retailers use their personal data in order to receive tailored and targeted products, recommendations, and offers.[116] Therefore, brands that personalise products are also able to build greater trust with their customers. However, even with all kinds of data and technologies at their disposal, businesses still struggle to create personalised experiences that will not drown their customers in too many options. At this point, powered by data, hyper-personalisation combines curation with personalisation to create customised user experiences around individual customer wants and needs.

With the internet and digital services pervading every walk of life, there is a clear shift from standardisation through mass manufacturing, towards personalisation through automation and smart manufacturing. With businesses becoming increasingly more customer-centric, the customer becomes the focal point of how manufacturing operations are engineered. In that regard, it may sound like science-fiction but the highly automated Adidas Speedfactory in Germany can quickly produce small-batch designs for specific markets by cutting the production cycle from months to a single day thus catching up to the speed of online ordering.[117] This reveals *Hyper-Personalised Manufacturing* as a trend in 3D print industry and when it becomes a reality, it plans to transform the way we shop and the prices we pay for our products.[118]

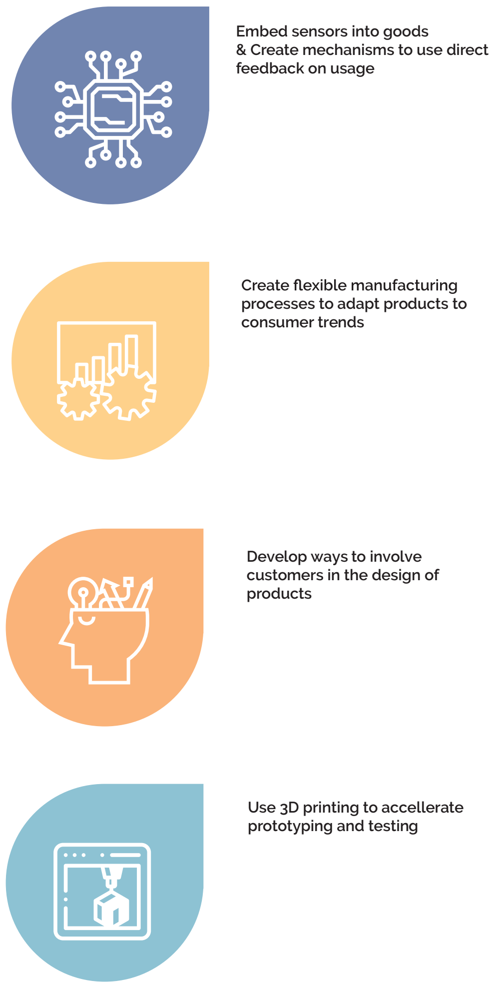
Adaptability to increased demand for personalised products and services, according to consumers' individual specifications, is becoming critical to market and value capture for companies around the world. To address these increasing personalised needs, the *Hyper-Personalised Manufacturing* of the future (See Figure 37) will focus on the following four key actions:[119]

- **Embed sensors into goods and create mechanisms to use that direct feedback on usage** to develop more personalised products
- **Use 3D printing to accelerate prototyping and testing** which can drastically speed up the time to market and responsiveness to changes in consumer demand
- **Create manufacturing processes which are flexible enough to adapt products** to rapidly shifting consumer tastes and trends
- **Develop ways to involve customers in the design of products.**

In addressing the personalised needs of customers, hyper-connected manufacturing firms of the future will be capable to:

- **Develop Affordable Customised Products** – deliver a much wider range of product specifications in shorter time frames at an affordable price;
- **Customise for Local and Global Markets** – with customers at the core, hyper-personalised manufacturing will facilitate local add-ons that create brand stickiness, while fostering inclusive growth for the country or region of the consumer. This is especially relevant for emerging markets, as it will allow local companies to be part of a high-tech, global value chain, thereby boosting their competitiveness and the overall national economy.

Figure 37 - Four Key Actions to Focus in Hyper-Personalised Manufacturing
(Source: World Manufacturing Forum)



Cloud Manufacturing: The Future of Manufacturing

Lin Zhang
Engineering Research Center of Advanced Manufacturing System of Complex Product, Ministry of Education, Beihang University, Beijing 100191, China
School of Automation Science and Electrical Engineering, Beihang University, Beijing, China
Xun Xu
Department of Mechanical Engineering, University of Auckland, Auckland 1142, New Zealand
Dazhong Wu
Department of Mechanical and Aerospace Engineering, University of Central Florida, Orlando, Florida, U.S

As a service-oriented, networked and intelligent manufacturing paradigm, cloud manufacturing maps manufacturing resources and capabilities to the cloud by virtue of technologies such as cloud computing, Internet of Things, service computing and Artificial Intelligence. This forms a cyber-physical-human system with interactions between virtual worlds and reality, which enables cloud-based sharing, collaboration and on-demand use of manufacturing resources and capabilities, and provides intelligent, efficient on-demand services over the full lifecycle of manufacturing.

Cloud Manufacturing has six unique characteristics:

Decentralised Resource Gathering and Optimisation: With virtualisation and service-oriented technologies, manufacturing resources and capabilities are gathered to form an enormous resource pool that can be expanded indefinitely;

- *On-Demand Use of Manufacturing Services: Providing clients with manufacturing resources and capabilities in the form of manufacturing services through the network at all times and places; supporting free trading, circulation and on-demand use of manufacturing resources and capabilities;*
- *Data and Knowledge Gathering and Sharing: Gathering data, models, experiences, and knowledge involved in manufacturing to support manufacturing innovation;*
- *Social Manufacturing: Bringing together small and micro-sized enterprises through dynamic alliances and crowdsourcing based on the cloud service platform. An enterprise itself may be small, but the unification of many such enterprises will create sizeable manufacturing capacity and capabilities;*
- *Highly Flexible Manufacturing: Forming a highly flexible virtual compliance production line through the intelligent combination of componential manufacturing services, achieving highly personalised manufacturing capabilities;*
- *Highly Personalised Manufacturing: Provision of personalised and customised services based on the capabilities stated above. In particular, the combination of cloud manufacturing and 3D printing provides strong support for truly individualised manufacturing.*
- *Corresponding to the three typical cloud modes (i.e. private cloud, community cloud and public cloud), Cloud Manufacturing also has three modes, namely,*
- *Private Cloud: A centralised mode in which manufacturing services are shared within one company and/or its subsidiaries;*
- *Community Cloud: A collaborative mode in which manufacturing services are shared between several organisations from a specific community with common commercial interests;*
- *Public Cloud: An open mode where a set of manufacturing services are made available to the general public.*
- *In the past decade, researchers worldwide have conducted extensive research into the theory, methods and technologies of Cloud Manufacturing, and made some practical achievements in some enterprises. Especially in China, some large-scale enterprises significantly enhanced design, production and management efficiency by implementing Cloud Manufacturing. Meanwhile, a number of companies specialised in cloud manufacturing. The industry chain of cloud manufacturing is on the way.*
- *However, generally speaking, research on and application of cloud manufacturing are still in the early stages. Although achievements have been made in the construction and application of the private cloud, the construction and operation of community and public clouds are still confronted with enormous challenges and uncertainty. Many technical problems remain unsolved. In the coming five*

years, the issues demanding prompt solutions are believed to be:

- *International standardisation, covering cloud manufacturing architecture, service specifications, implementation methods, resources and capability access and communication, resources and capability virtualisation and servitisation, service transactions, security and credibility;*
- *Application of AI in cloud manufacturing to give rise to more intelligent cloud manufacturing;*
- *Establishment of a truly flexible supply chain system by virtue of the cloud manufacturing platform, incorporating the intelligent edge management and control system to realise true low-cost customised manufacturing.*

Fundamental research is required to achieve these goals, such as quantitative analysis of cloud manufacturing business models, credibility assurance of cloud manufacturing services, dynamic composition and scheduling of manufacturing cloud services, knowledge management and big data analysis in cloud manufacturing, 3D printing based on cloud manufacturing platforms, cloud manufacturing security systems, cloud manufacturing and energy and environment.

As a novel manufacturing paradigm, cloud manufacturing represents a development trend of manufacturing and it is considered an effective approach to achieving service-oriented, green, intelligent, socialised and agile manufacturing. In the new era of Industry 4.0, the Internet of Things and smart manufacturing, cloud manufacturing has a unique role to play.

Global Risks-Resilient Manufacturing

Future-oriented, *Global Risks-Resilient Manufacturing* systems will be able to recover their functions in the realities of global risks via strategic decision making and business model upgrades considering hyper-connectedness of value creation chains to reinforce cybersecurity, exploit Social IoT systems, integrate blockchain technologies, involve all stakeholders in the digital value chain, and respond to off-shore threats while adapting to changing market needs by virtue of its capacity to overcome any disruptions that may occur.

Being faced with the challenge of overcoming data and cybersecurity concerns in a world where high volumes of sensitive data move over the internet, it is of utmost importance to shift towards the future-oriented resilient manufacturing systems. They are able to recover their functions in the realities of global risks via strategic decision making and business model upgrades taking into consideration hyper-connectedness of value creation chains. To achieve this goal, *Global Risks-Resilient Manufacturing* focuses on five main pillars (See Figure 38):

- **Reinforcing Cybersecurity:**[120] Within the *Fourth Industrial Revolution*, the Internet of Things is the key to connecting people, machines and systems. However, an increased interconnection and integration within global systems also means increased dependencies, and thus vulnerability as moving large volumes of competitively sensitive data over the internet heightens the need for data and cybersecurity. Existing cybersecurity products and solutions designed to secure information technology systems do not address the cyber threats that target an interconnected system of suppliers and customers. To address these information security concerns, future manufacturing enterprises will utilise specialised secure data-sharing services by adopting mechanisms to facilitate intra- and inter-industry collaboration. Accordingly, factories of the future will have an extensive focus on manufacturing-specific cyber-security needs in five priority areas, i.e. system-level security and cyberresilience, integrity of manufactured goods from design through the factory floor, securely connecting the factory to the supply chain, cyberintelligence, and machine-to-machine security including legacy systems.
- **Exploiting Social IoT Systems:**[121] Social IoT (SIoT) is an emerging paradigm of IoT in which different IoT devices interact and establish relationships with each other to achieve a common goal. In essence, SIoT adapts a service-oriented architecture where heterogeneous IoT devices can offer or request autonomous services and collaborate on behalf of their owners. To mention a few examples of improved productivity to be generated by Social IoT in the future of manufacturing, a machine can order its own replacement parts so it never has to stop again for a refill or can arrange its own preventive maintenance based on real-time diagnostics, sending the message to the nearest or next available engineering team.
- **Integrating Blockchain Technologies:**[122] Blockchain is a distributed database, whereby transactions are securely encrypted and replicated across many computers in multiple copies of a ledger. Once data is written to the chain it is committed into blocks and these blocks are in turn committed to the chain. Because of the architecture, once data is written it becomes nearly impossible to change, making it a very secure system for storing digital assets. In the short term, manufacturing companies will use blockchain technology mainly for smart contracts, process transformation, supply chain tracking, asset sharing, track and trace, warranty management (e.g. track the vendor source of any defects and detect counterfeit goods) and so on. However, the future of manufacturing will see the rise of the blockchain technology integrated into the entire manufacturing operations and value chain, eventually leading to a situation where supply chains become demand chains and the manufacturing process itself becomes distributed, aligned with the future-oriented manufacturing vision.
- **Involving All Stakeholders in the Digital Value Chain:** Understanding grand challenges and to transform them to opportunities is one of the priorities of the global risks-resilient manufacturing paradigm. In that regard, future manufacturing systems will be resilient and adaptive to rapidly changing and unpredictable environments with the capacity to overcome disruptions and adapt to meet the changing market needs. Hence, joint efforts of multiple actors from many sectors across various governance levels will accomplish the vision of a globally leading and resilient manufacturing system. Humans will still play a key role in the future of manufacturing, being well-prepared for changing job requirements and

life-long learning contributing to increasing sustainability in a global context.

- Responding to Off-Shore Threats: Besides addressing the aforementioned challenges, the future manufacturing enterprises will also offset offshore threats by adapting their business models and strategic decision-making mechanisms towards increasing onshore manufacturing therefore contributing to advancements in all pillars of global sustainability.

Figure 38 - Five Focus Points of Global Risks-Resilient Manufacturing
(Source: World Manufacturing Forum)

Circular Manufacturing

As an emerging paradigm in the context of zero-waste in the factories of the future, *Circular Manufacturing* perpetuates reuse of resources in the form of materials and energy via ingenious design of socio-technical systems and effective use of information to deal with challenges such as resource scarcity, waste generation, and pollution by managing the whole lifecycle of a manufactured product from inception, through engineering design and manufacturing, to service and recovery, thus sustaining future businesses.

The circular economy is fast becoming an active and rapidly expanding mainstream trend as ever more companies realise the real value and profits of this new, more sustainable way of doing business. A regenerative model in which manufacturers find ways to use materials and goods for a much longer time period, creating more than one product lifecycle, fuelled by new digital technologies and new financing models, is driving forward this great innovation: the circular economy for manufacturers. This kind of innovation goes to the heart of what it means to be human: generating wealth and success but in the context of respect for the planet, supporting its survival for future generations. Manufacturers are really at the core of this new revolution and their efforts to shift to circular models, as some are starting to do, represent one of the greatest innovative challenges of our times. The circular manufacturing system is intentionally designed for closing the loop of products or components through multiple lifecycles via a value management approach including the phases of value creation, delivery, use, recovery and reuse in a systemic perspective. In that regard, the future of manufacturing will see a gradual development towards a high-quality circular manufacturing industry, in which the demand for (scarce) raw materials is met by raw materials from the value chain wherever possible, considering the following five strategic goals (See Figure 39):

- Redesign Products and Materials Selection Suitable for Reuse (e.g. shift from critical raw materials such as metals and minerals to generally available raw materials)[123]

Many companies use critical metals and minerals for their increasingly complex products. As this entails long-term risks, we need to explore ways of using generally available metals and minerals as substitutes. The shift towards a circular economy starts with rethinking the initial design and manufacturing of the product, considering the product's second life reutilisation or materials' recyclability. In the future of manufacturing, re-engineering the products to minimise waste and to enable the recycling implicit in circular manufacturing will become a necessity. Toward this purpose, de-manufacturing facilities will handle a high variety of products in different life cycle stages, whereas remanufacturing plants will be the main driver towards the increase of reuse, repair and remanufacturing of products, providing instrumental goods, technologies and know-how to manage these phases.

- **Conserve and Recover Resources from the Used Products**, **and Use them in Manufacturing of New Products** (e.g. increase efficiency and high-grade sustainable reuse of materials in all steps of relevant value chains)[124]

Harnessing data allows companies to put a value on waste in all its forms and monetise that waste through products and services that delight customers and generate significant new revenue growth. Increasingly, manufacturers are seizing these new opportunities offered by the Internet of Things and in some cases, shifting to a more service-based model in the process. In that respect, manufacturing companies should develop processes and systems for taking back and refurbishing goods for a second life cycle. Here, the tracking technology could revolutionise manufacturers' ability to do this. They need to understand the material flows of their products, so that they can plan and facilitate the next cycle. Advanced monitoring is being brought into reality by the new technology wave of chips and sensors that will monitor things, feedback information and enable machines to talk to other machines, known as the Internet of Things. This new capability is driving revolutionary change among manufacturers, many of whom are already keen to use it to optimise production processes and improve customer service. In the future, a web-enabled collaboration platform can be envisioned in which data and knowledge about whether a particular waste is recyclable or transformable into a useful resource can be shared among manufacturing companies, recyclers, and product designers. Using such a web-based platform means the manufacturing wastes or by-products are physically exchanged between different companies from within and across industries thereby waste-to-resource matching is dynamically facilitated. Moreover, decisions can be made based on the economic and environmental viability of the exchanges. Challenges for this development include codifying the vast and growing amount of tacit knowledge on a multitude of manufacturing wastes and resources.

- Develop New Ways of Production[125]

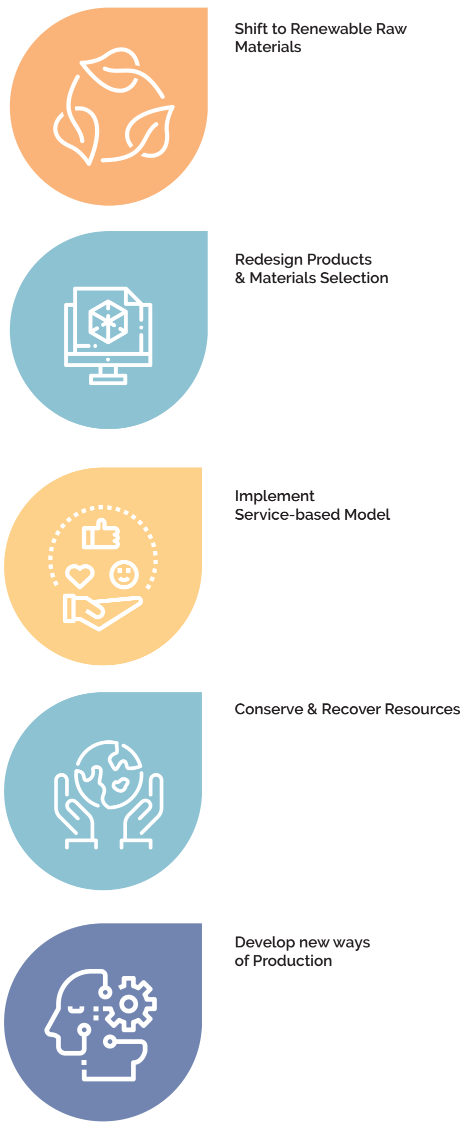
The future global economy of products and services calls for large volumes of primary raw materials and energy. Accordingly, we will need new production systems using sophisticated printing technologies (for example, printing food) and includes products made of self-healing and shape-shifting materials that can prolong their shelf life. The demands of *Circular Manufacturing* imply change to materials, machines, products and processes; all of which will impact job design. In the future of manufacturing, re-engineering manufacturing processes to be more efficient will be necessary to reduce the emissions and other waste, making circular manufacturing a dominant philosophy for an enhanced product life span, more efficient use of resources, and elimination of waste and pollution during the manufacturing process as well as life of the product.

- Implement a Service-Based Model for Circular Products[126]

Along with the supply side, the demand for circular products and services will need to increase in order to complete the circular business cases. Companies and governments play a key role in this by adopting socially responsible procurement. In the past, manufacturers have sold assets to customers. This seemed to make most sense. But in a world where you want to minimise waste, it is far better for the producers to retain ownership, selling instead a service to the customer. For customers, this tends to mean they get a better service overall with maintenance and quality at the heart. Manufacturers in turn can ensure they service and maintain the product and keep it in a good condition, prior to its next cycle. The future manufacturing enterprises will therefore explore the full range of new collaborative, circular and servitised business models and supply chains, focusing on re-use, re-manufacturing and recycling where products or components are leased and then returned.

- **Shift from Fossil to Renewable Raw Materials and Eliminate Use of Toxic Chemicals**[127] The circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the *end-of-life* concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and business models. In the near future, fossil carbons can largely be replaced by short-cycle carbons. This has already been achieved on a small scale with heavy chemicals such as ethanol, methanol, butanol, and acetic acid. When properly used, this contributes to reducing CO_2 and reduces dependency on scarce or volatile raw materials.

Figure 39 - Five Strategic Goals of Circular Manufacturing
(Source: World Manufacturing Forum)



Inclusive Manufacturing

Inclusive Manufacturing empowers individuals of any gender and age from all social, economic and cultural strata by involving them in diverse activities related to manufacturing. This is achieved through fostering required skill sets of future workforces, enhancing innovation in rural places, boosting open-source designs for products benefitting individuals of a very large and heterogeneous customer base, promoting innovative business models for easier access to markets, and providing all other necessary interventions to ensure inclusive innovation.

In today's technology-intensive world, manufacturing is transforming rapidly and one of the most important modern manufacturing challenges is the development of sustainable product service systems to be accessed and used by a large and varying customer base. This can be addressed by the key aspects of workforce diversity, sustainable manufacturing operations, and human-centric automation. Guided by this challenge, the current manufacturing paradigm emphasises inclusivity of manufacturing drivers across the entire value chain where the contemporary manufacturing ecosystem needs to consider socially inclusive development, offering equal opportunities and an equitable distribution of benefits, community involvement, value-based engineering, responsible innovation, product lifecycle management, and planning for end-of-life recycling or reuse. Existing and emerging technologies play a major role in developing and managing such an inclusive manufacturing paradigm of sustainability. Some of these technologies include manufacturing micro-shops, computer-aided product lifecycle management and engineering, smart supply chain management, cloud-based access to open designs, digital distribution platforms, and other innovative mechanisms.[128,129]

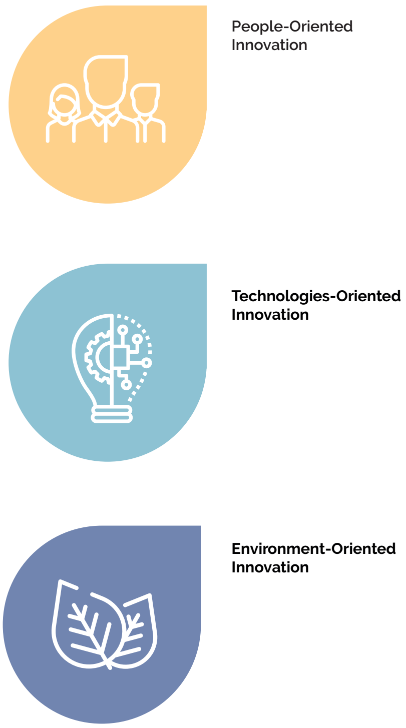
In this context, *Inclusive Manufacturing* (See Figure 40) comprises three dimensions:[130]

- **People-Oriented Innovation:** Sustenance and employment of all categories of people in numerous manufacturing activities irrespective of their gender, age, social, economic, and political status enabling all to take part as stakeholders, i.e. designers, manufacturers, trainers, marketers, users and so on for inclusive innovation.

- Environment-Oriented Innovation: Deployment of a wide variety of activities during the whole life cycle of a product to enable a sustainable economic growth without harming the environment thus promoting inclusive and sustainable industrialisation.

- Technology-Oriented Innovation: Identification and adoption of proper and efficient enabling technologies at all levels (basic to cutting-edge) which reduce drudgery while creating new jobs hence fostering and sustaining inclusive innovation and manufacturing.

Figure 40 - Three Pillars of Inclusive Manufacturing
(Source: World Manufacturing Forum)



Rapidly Responsive Manufacturing

Rapidly Responsive Manufacturing is a predictive, agile, flexible and lean model of production that reacts quickly to and takes advantage of changes in market conditions, customer preferences, manufacturing conditions and social demands for enabling rapid innovation, quick response to market demand signals, and consistent, high-quality, socially responsible operations - all of which contribute to the ability to run smarter, faster, and simpler processes allowing manufacturers to maintain a comprehensive product portfolio while reducing cost of production.

In the future of manufacturing, the emergence of several game-changing technologies – from IoT to collaborative robotics, and from big data analytics to additive manufacturing and 3D printing – will make the plant floor much more efficient and the next step will entail creating higher levels of agility, rapid responsiveness and innovation, with the fundamental support of technology and human skills. Accordingly, manufacturers of the future will move away from today's exclusive focus on efficiency and pay closer attention to fulfilment of customer needs. Efficiency will still be important in the future but meeting customer needs with higher levels of flexibility will be a greater priority. In this context, making factories agile and responsive will be a quintessential capability, and such a shift will require the adoption of principles including proximity to demand, postponement of variability and centres of excellence, along with a massive change in mind-set.[131] In this regard, *Rapidly Responsive Manufacturing* will respond quickly to and take advantage of changes in market conditions, customer preferences, manufacturing conditions, rapid innovation and social demands. Achieving *Rapidly Responsive Manufacturing* requires adaptive and responsive production facilities that can respond to more than 70% of changes in volume, adapt quickly and flexibly to supply chain decisions, including relocation of production to places where economies of scale can be achieved, and reduce concept to market time significantly.

Industry 4.0 is the application of technologies that are enabling the creation of more flexible and rapidly responsive manufacturing to better serve the needs of customers. The concept of make-to-order manufacturing and mass personalisation requires flexible factories that rely on interactive communication with all participants in specification and production; including customers, purchasing, supply chain, machines, production line equipment, and workers. Responsive manufacturing enables innovation, quick response to market demand signals lower total manufacturing costs and consistent, high-quality, socially responsible operations — all of which contribute to the ability to run smarter, faster, and simpler.[132]

With the onset of globalisation, manufacturers should serve diverse markets, meet customer expectations along with ensuring timely production and manage complex supply networks that have replaced the traditionally-linear supply chains in order to maintain positive brand image in the age of instant communication. In this respect, rapidly responsive manufacturing is the way for manufacturers to address these challenges and stay competitive in the industry. In *Rapidly Responsive Manufacturing*, companies follow a predictive, agile, flexible and lean model of production. From innovation to delivery, the entire product lifecycle is streamlined to produce quickly and only the required quantity, meet the quality expectation, and eliminate redundant costs; all while having the capability to scale and adapt according to the change in the demand. In *Rapidly Responsive Manufacturing*, an entity enters into production only when there is a requirement. The methodology enables manufacturers to maintain a comprehensive product portfolio while reducing cost of production by eliminating shadow expenses. Lastly, the constant inflow and analysis of market data ensures that the product meets the quality and compliance standards of the customers and the government.

Consumer demand for innovation, shorter product life cycles, scarcity of raw materials, and changing regulations are just some of the many challenges that manufacturers face today. Increased margin pressures have driven companies to find ways to lower material, manufacturing, and support costs, while improving the efficiency of manufacturing and delivery. On top of that, demand levels can change rapidly, compounding the volatility around manufacturing processes as companies struggle to meet demand before the tides shift again. In this environment, successful companies are those that can coordinate flexible, and *Rapidly Responsive Manufacturing* within the value chain. That's why enabling *Rapidly Responsive Manufacturing* across the design, plan, and production parts of the manufacturing life cycle are such crucial components to improving execution, operations, and user experience.

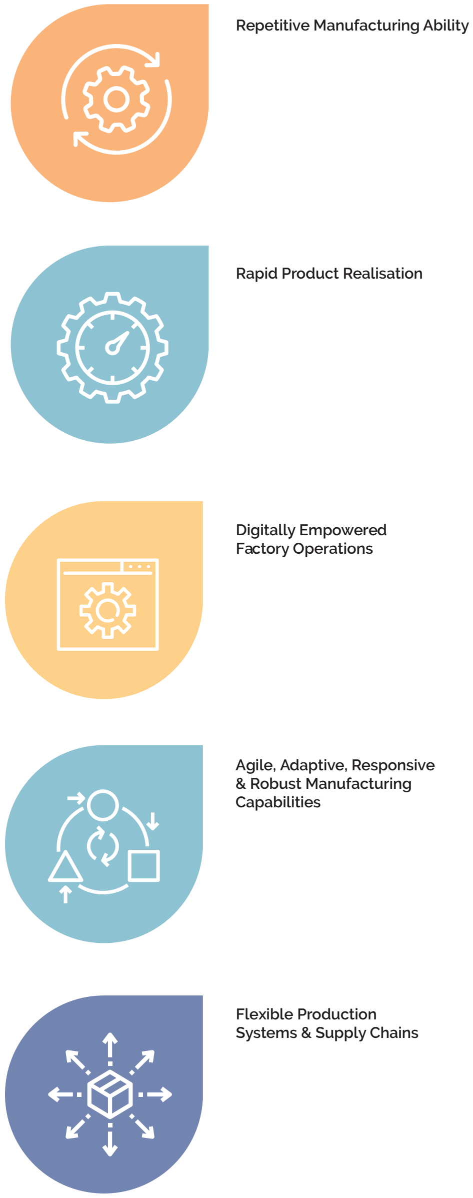
Being a rapidly responsive company is one of the most useful and necessary capabilities in today's competitive markets. In the context of manufacturing, responsiveness has been referred to as the ability of a manufacturing company to respond rapidly to customer demands and market changes. Hence, it is crucial for manufacturing companies to acknowledge the fundamental elements of responsiveness in their operations as it has significant impact on company's competitive priorities mainly the delivery speed.

The key qualities and characteristics required to achieve *Rapidly Responsive Manufacturing* (See Figure 41) include:[133]

- **Agile, Adaptive, Responsive and Robust Manufacturing Capabilities**: To stay competitive, manufacturing companies must be able to react to unpredictable market changes, shorter time-to-market and rising product development costs. Therefore, manufacturing firms need to rethink their production systems to more rapidly respond to customer requirements and to better manage production capabilities.
- **Digitally Empowered Factory Operations**: As the digital economy is revolutionising every aspect of life and business, the factory of the future will be digitally infused, providing tightly interconnected information and production flows.
- **Flexible Production Systems and Supply Chains**: The volatility of the global environment has led to major changes in the traditional manufacturing supply chains affecting decisions related to production levels, raw materials supply strategies and transportation capacity. Manufacturers will need to make supply chain-related decisions more quickly and flexibly in the face of more volatile demand.
- **Rapid Product Realisation**: Improving the path from concept to commercial viability is an important challenge for future manufacturing competitiveness. Companies able to drastically reduce the time from customer demand to delivery will gain significant competitive advantage.
- **Repetitive Manufacturing Ability**: To optimise repetitive manufacturing, a form of mass production that relies on

making high numbers of identical units in a continuous flow, companies need robust manufacturing, integrated planning, and real-time visibility capabilities. These capabilities enable users to manage optimised production allocation across the manufacturing network and rapidly adjust to changes in demand, supporting efforts to track production completion, material usage, and quality metrics during execution.

Figure 41 - The Key Qualities and Characteristics Required to Achieve Rapidly Responsive Manufacturing.
(Source: World Manufacturing Forum)



The Brazilian Call for Action

João Emilio P. Gonçalves
Executive Manager, Industrial Policy Unit, National Confederation of Industry - Brazil

The emergence of the so-called Industry 4.0 has been transforming industrial production with new processes, products and business models that were unthinkable a few years ago. This phenomenon, which was named as such to refer to the Fourth Industrial Revolution, holds the promise of making conventional production models gradually inefficient.

The technologies can be combined in different ways and this revolution can have a wide range of impacts, which will vary from company to company according to the technologies they adopt, their degree of integration and their business strategies. For most companies, this process will be gradual and customised according to the investments they make and to their existing technological and productive capacity. This transition may include integrating technologies into machines and equipment in use by, for example, implementing sensors, software and buying new production assets, as in the case of additive manufacturing and robotics.

This new industrial revolution will bring about significant impacts on production, such as increased efficiency in the use of resources, greater ability to integrate and increased flexibility in production lines. It will also imply transformations in business management, mainly in two aspects. The first one is related to the strategy adopted to implement technologies, such as cooperation between IT and production units. The second one is associated with the results of adopting these technologies, which require companies to develop and/or improve their business models, especially in regards to their relationship with suppliers and customers.

Major industrialised nations have placed the development of Industry 4.0 at the heart of their industrial policy strategies with the aim of preserving and increasing their competitiveness.

The speed at which the enabling technologies of this revolution are being disseminated suggests that the arrival and consolidation of Industry 4.0 will also be much faster than similar cases in the past. The ability of Brazilian industry to compete internationally will therefore depend on our ability to foster this transformation. Initially, this need will be more pressing for some sectors than others, but it will eventually be felt by all of them.

The Brazilian industry's ability to compete internationally depends on how companies will react and on the extent to which the government, in partnership with the private sector, will be able to promote this transformation and not create obstacles. This need will be imposed on some sectors sooner than on others. Initiatives aimed at developing Industry 4.0 in Brazil should focus on strengthening companies that will transition earlier to the new model and on encouraging the others to accelerate their move to the new technological wave.

The main recommendations include:

- *Needs and opportunities for the application of digital technologies in production chains should be raised, considering the diversity and differences in companies' development stage.*
- *Policies designed to disseminate and induce the adoption of new technologies should be prioritised. Specific mechanisms to promote technological development should be made available, favoring digital technologies based on the specific challenges for Brazil's development.*
- *Telecommunication infrastructure, especially broadband, should be expanded and improved.*
- *Regulatory aspects affecting the development of Industry 4.0 should be improved.*
- *Strategies for training and reskilling human resources should be developed.*
- *A governance model should be established to foster institutional links between the public agencies in charge of implementing Industry 4.0 and digitisation policies, as well as links between the public sector and companies, which is key to addressing the different situations faced by industry.*

World Manufacturing Forum

WMF

10 Key Recommendations by the World Manufacturing Forum

1. Cultivate a Positive Perception of Manufacturing
2. Promote Education and Skills Development for Societal Well-being
3. Develop Effective Policies to Support Global Business Initiatives
4. Strengthen and Expand Infrastructures to Enable Future-Oriented Manufacturing
5. Encourage Eco-Systems for Manufacturing Innovation World-Wide
6. Create Attractive Workplaces for All
7. Design and Produce Socially-Oriented Products
8. Assist SMEs with Digital Transformation
9. Explore the Real Value of Data-Driven Cognitive Manufacturing
10. Promote Resource Efficiency and Country Specific Environmental Policies

1. Cultivate a Positive Perception of Manufacturing

As manufacturing becomes a highly digitised and technical sector, industry no longer contains the dirty and laborious jobs often associated with the past. Instead, a manufacturing career provides a highly advanced and rewarding work environment that can lead to a fulfilling and fruitful life. As a result, public and private stakeholders must work to help cultivate a positive perception of manufacturing in order to attract more talent to enrol in manufacturing education programs and maintain a life-long manufacturing career. Creating a strong and stable reputation of manufacturing is the basis for establishing the future-oriented development considering the global prosperity and well-being.

First, information regarding manufacturing must be readily available within society. Awareness of manufacturing and societal megatrends will help the general public gain a better understanding of the current state of manufacturing and how manufacturing jobs are not only personally rewarding but also contribute to global well-being. Therefore, it is necessary to communicate, campaign and promote a positive image of manufacturing. If talent is aware of the opportunities available in the manufacturing industry, then they will be more likely to consider and ultimately choose manufacturing as a future career path.

Cultivating a positive perception of manufacturing can start with small steps such as making manufacturing more apparent in everyday life. Increasing representation of manufacturing in society through popular means of culture and communication such as books, television, movies and other multimedia can help to promote a more positive image. For example, if a television show features an industrial engineer then manufacturing is represented more in society and therefore helps to further cultivate a positive perception. Public and private entities can also work to create campaigns that showcase the benefits of a career in manufacturing in order to attract new talent. It is vital that manufacturing be perceived as an appealing career choice for future generations by creating high value jobs and providing a positive work environment. If young talent is drawn to manufacturing, then a greater talent pool will help lead to more progress, innovation and a stronger sector.

Innovation should also be promoted as an element of a manufacturing career. In a time when start-up companies are perceived as trendy and appealing by young talent, manufacturing should highlight opportunities to innovate and create within industry. The start-up incubator model can be applied to manufacturing to help promote a positive perception of manufacturing. In this model, manufacturing related start-ups are incubated within larger companies and organisations to allow for creativity and mitigated risks that can lead to great innovations and breakthroughs. By showcasing manufacturing as a modern industry that has many opportunities for creativity and innovation, more talent will be attracted.

Additionally, a positive perception of manufacturing should also be cultivated among instructors as well as new talent and students. In order to have a robust and well-educated manufacturing workforce, talented instructors are also needed to provide quality education. If both instructors and students perceive manufacturing as a valuable sector with opportunity, then industry will flourish with a greatly educated workforce and apt instructors. Cultivating a positive perception of manufacturing is key to encourage all to consider manufacturing as an appealing and dynamic career path.

2. Promote Education and Skills Development for Societal Well-being

In the wake of the *Fourth Industrial Revolution*, technological innovation is moving forward rapidly at unprecedented rates. As a result, the scope of skills needed to meet industrial needs has been extended. Workers and key decision-makers must understand new skills needed and remain updated on trends or they risk falling behind the pace of innovation. Skills that were once considered specialised are now becoming basic skills necessary for jobs in the industrial sector. These now crucial skills must be developed as soon as possible starting with primary education and continuing throughout the doctoral or equivalent level. Additionally, current workers must be retrained, upgraded and up-skilled to meet new demands. Further, skills necessary for manufacturing jobs are moving from manual to more cognitive based skill-sets and therefore require new competencies to maintain and troubleshoot intelligence systems such as robots, AI, and advanced manufacturing. Artificial Intelligence has a growing knowledge level that will require more skilled workers who need to be educated and trained to develop, maintain and troubleshoot systems. Since workers will be managing computers and machines that are increasingly intelligent, employees must be trained to work at a similar level of new smart technologies.

However, the industrial workforce is not the only group within society that must be trained to deal with new technologies. The general public must also be educated as advanced technology is becoming embedded in every facet of life. In order to avoid people becoming overwhelmed by machines, everyone needs to be more prepared for these new technologies and challenges. The need for more education across multiple domains is due to the fact that technology will be a vital part of daily life. Workers will not only compete among human talent but also with machines and AI algorithms. As a result, education is increasingly relevant compared to the past.

In order to enable all workers to succeed in a rapidly advancing workplace, changes to the educational process should be considered. In addition to traditional manufacturing skills, new relevant skills should include emphasis on competencies such as analytical reasoning, system and computational thinking, emotional intelligence, communication and team-working skills, entrepreneurial mind-set, data search and analysis. All nations are urged to promote and improve education programmes in order to meet new skills requirements. National agendas should take note that to empower and enable all workers, they need to not only create a better education system but also must retain educated workers in order to receive a return on their investment in education. Satisfying key needs such as a safe and enjoyable living environment must be met in order to keep educated workers.

Additionally, universities and other academic institutions should revise their programmes according to necessary new skills and update their teaching processes to include new methods such as learning factories. There must be more and improved collaboration between educational institutions, industry, industrial and workers' associations. This collaboration should be incentivised by public authorities to allow for a workforce with comprehensive skill-sets. Finally, manufacturing education should be promoted within Lesser Developed Countries (LDCs) while remaining cognisant of issues such as accessibility.

3. Develop Effective Policies to Support Global Business Initiatives

Effective policies are key to enable manufacturing business to flourish. They provide the guidelines, regulations and the proper funding for research & development necessary to allow for quality and safe production that helps to bolster the world economy. Given the current manufacturing paradigm, it is more important than ever to encourage public stakeholders to develop effective policies and funding schemes so that manufacturing can continue to flourish and grow, enabled by improved manufacturing processes and related industrial machinery.

Clear regulations and policies are necessary to help companies make investment decisions over a long period of time despite uncertainty. This allows organisations to innovate and engage in Research and Development (R&D) since they are aware and understand the regulations that are pertinent to their area of manufacturing. If policies do not exist or are unclear, investments in R&D can be hindered since the regulatory future of a newly developed product may be unclear. As a result, it is necessary to have transparent policies that are easily accessible and understandable by the private sector to order to encourage innovation and further bolster the manufacturing industry.

Further, policymakers should support the development of technologies that enable a strong manufacturing sector for sustainable development and job creation. Policymakers should consider a wide-array of needs and issues to help manufacturing business grow. For example, new funding schemes to support the innovation in industrial manufacturing machinery. Or, new types of social support programmes are needed in order to take care of those who are not able to keep pace with the rate of innovation. Global standards and regulations should be developed for efficiency and to create more opportunities for innovation and development. National, regional, and global networks should be created for skills development and to encourage innovation, knowledge, and education in order to address the skills gap. A new safety regulation system is needed for human-machine interaction, particularly with robots and other similar technologies. Governments should encourage a more flexible job market with regard to skills and support worker retraining and further education. Responsible trading policies should be encouraged to further enhance cooperation in global supply networks. Re-shoring policies and initiatives to support local job growth should also be considered. Additionally, regulations for new disruptive technologies should be developed in areas such as robotics, virtual and augmented reality, data privacy and security, and AI. All of these regulations should be considered and implemented in a way as to not hinder innovation, growth and progress.

Finally, policy frameworks should be created across industrial sectors and potential policies should be discussed with a diverse set of industrial representatives. In order to ensure that policies help all manufacturing businesses to flourish, it is imperative that these policies be carefully considered with regard to potential impact. Effective policies are necessary for a manufacturing sector to succeed and grow. It is key that all nations consider their domestic industrial policies to help promote growth and spur innovation.

4. Strengthen and Expand Infrastructures to Enable Future-Oriented Manufacturing

Physical infrastructure has been the backbone of industrial societies for the first and second industrial revolutions. With new technology and progress, digital infrastructure has become the backbone of the third and now *Fourth Revolution*. Now, both physical and digital infrastructure are equally important to enable future-oriented manufacturing and maintain pace with innovation. While nations have a wide-array of infrastructure capability, domestic policies should aim to support physical improvements until needs are met and then scale up to develop a robust digital infrastructure.

Well-developed physical and digital infrastructures help to prevent a digital divide from occurring. Digitalisation is an enabler of progress and industrialisation and therefore decreases the divide between nations, regions, and socio-economic standing. When implementing new physical and digital infrastructures, cultural and geographic aspects must be considered in order to advance progress.

Strengthening and expanding digital infrastructure not only happens at a national policy level but also at a more localised company level. Digitalisation is a driver of competitiveness in the manufacturing paradigm and helps to push future-oriented manufacturing forward. As a result, digitalisation should be present in all stages of the product life-cycle from development to final delivery to consumers. By strengthening infrastructures, particularly with regard to digitalisation, companies remain relevant in a competitive market and help to enable future-oriented manufacturing which in turn will help to improve and transform industry.

Further, digitalisation is a driver of servitisation which helps to bolster the new shared economy. Servisation is a key element of modern economies and works in tandem with manufacturing to help create more jobs and spur economic progress. Servitising products helps to create more efficient and effective practices that are beneficial both to manufacturers and consumers. In order to continue to servitise products, infrastructure is necessary and therefore must be strengthened and expanded.

Additionally, digitalisation should be perceived as a means for the wide adoption of the circular economy paradigm. Digitalisation and digital infrastructure help to make processes and products leaner and greener through material reuse and zero-waste manufacturing. Incorporating digital processes into production and design help to eliminate waste and help manufacturers make more environmentally-friendly decisions that are sensitive to societal needs. Thus, digitalisation is necessary for the prevention of environmental harm, natural resource over-exploitation and in order to promote social wellbeing. By incorporating digital infrastructure into production, future-oriented manufacturing is enabled and driven forward through improved processes and impacts.

Finally, it is key to note that as physical and digital infrastructure are being expanded and strengthened in both the public and private sector. Since digital and physical infrastructure are now highly intertwined, cybersecurity must be considered in all elements of expansion and strengthening of new and current infrastructure in order to maintain safety and integrity of systems. In order to advance and enable future-oriented manufacturing, cybersecurity must be considered to allow for safe and efficient systems that help to promote progress and wellbeing. Without proper security measures in place, both physical and digital infrastructure risk being compromised.

5. Encourage Eco-Systems for Manufacturing Innovation World-Wide

Eco-Systems for manufacturing innovation include new forms of collaboration, partnerships, knowledge-sharing, and co-innovation among a vast network of trusted and transparent partners including companies, research associations, public bodies, and individuals. It is imperative for public and private stakeholders to promote and encourage these systems to allow for collaboration and progress. Eco-systems provide the means to take bold steps and encourage risk in order to create disruptive and paradigm-changing technologies.

Eco-systems should be utilised to create new socially-oriented products and services to innovate within global supply networks and enable co-creation and growth. When resources and knowledge are pooled, advancements for the betterment of the entire population become possible. It is also important to create eco-systems that are sensitive to potential cultural divides that can be accompanied with new technological adoption. In order to create a more connected and peaceful world these systems must have a great amount of thought and sensitivity in their actions. It is important to enable these eco-systems to be able to address potential cultural issues and to minimise divides throughout the world.

Further, stakeholders must encourage innovators and entrepreneurs to engage in manufacturing eco-systems in order to benefit from advanced manufacturing technologies. Knowledge-sharing and collaboration can benefit both those directly in the manufacturing industry and other business stakeholders. By having a wide array of innovators and experts in a manufacturing eco-system, more well-developed knowledge will be available to help create, produce, and provide guidance.

Additionally, innovation can be created through smaller eco-systems with start-ups. Larger companies can serve as a point of guidance and should help to incubate start-ups in order to spur high-risk research and innovation. Nations should encourage companies to take on responsible risk through R&D within start-up ventures. By encouraging innovation within a wider context of a manufacturing eco-system more innovative technologies will be produced, available, and usable by many and therefore help to promote manufacturing and the global economy. Manufacturing eco-systems are a vital part of a well-rounded manufacturing sector that will help to expedite R&D and innovation.

6. Create Attractive Workplaces for All

Creating safe and healthy workplaces is a vital pillar of any industrial sector. However, in competitive economies, workplaces must not only meet basic needs but also be appealing to potential talent and workers. Attractiveness of the workplace helps to improve competitiveness and meet all the needs of workers. An attractive workplace must promote well-being through health, safety, comfort, positive socialisation, diversity, and fair compensation. The more appealing a workplace is the greater amounts of talent a company will have to choose from therefore allowing them to select high-quality employees that will help to improve processes and stay competitive. Both the public and private sector must work to create attractive workplaces that provide a positive environment for workers.

Attractive workplaces should also promote inclusion through equal representation regardless of race, colour, religion, gender, age, disability, sexual identity and national origin in order to drive innovation forward and create value. Organisations are advised to invest in all workers through the promotion of diversity awareness, equal educational access, safe and accepting work environments. Similarly, companies are urged to encourage human resource management practices to promote diversity and inclusiveness among workers.

Factories will be designed to provide an appealing and challenging environment for humans. The paradigm of *Human Centred Manufacturing* should be developed according to the development of new technologies, new interfaces between humans and machines and between machines to enable new levels of cooperation. New technology will not replace humans in creativity and decision power in key areas: technology will support human activity and augment their capabilities to higher levels of effectiveness and value added. Machines should adjust to human beings and not the reverse.

Similar to creating inclusive and attractive workplaces, stakeholders must also consider the attractiveness of workplace beyond their walls with regard to location, work-life balance and quality of life. With the advent of urbanisation, the so-called Urban Manufacturing trend is creating workplaces close to residential areas resulting in shorter commuting time, less environmental impact and a better work-life balance. Urban Manufacturing should be considered as an important characteristic in the context of smart cities and plays a role in improving the image and attractiveness of manufacturing.

In order to create a comprehensively attractive work environment, cities are competing amongst each other to bring in new businesses and maintain current companies. Manufacturing is driving this competition and helping to create more attractive environments for workers in both their personal and professional lives. Cities must become more attractive to companies and workers by providing well-functioning services such as public transportation, healthcare, education, public safety and cultural life. By creating an attractive environment both within a company and in regional environments, the manufacturing sector can recruit and maintain top talent to bolster competitiveness.

7. Design and Produce Socially-Oriented Products and Services

Socially-oriented products serve as a mechanism to help satisfy particular consumer needs and promote greater social impact. Accessible and affordable personalised products help to meet the needs of specific segments of society. In order to promote societal well-being throughout the globe, more socially-oriented products should be designed and produced. Both private and public stakeholders can help to promote the production of these products to help foster greater well-being globally.

It is key to improve design and production processes in order to lower the price of goods for fundamental knowledge sharing. High-technology items such as computers, tablets, and smartphones have now become fundamental tools in order to access knowledge and engage on a global scale. Products that help to promote knowledge sharing are socially-oriented in that they help to uplift, educate, and provide opportunity for all who have access to those technologies and connectivity capabilities. By creating better design and production processes for knowledge sharing goods, these products become more accessible to a wider range of peoples, breaking down barriers and making the world more interconnected and informed. Stakeholders are well advised to make socially-oriented goods that promote knowledge sharing more accessible in order to promote global connectedness and well-being.

Further, stakeholders are also encouraged to use new manufacturing processes to improve medical care and medical technology production in order to promote global health and well-being particularly in lesser developed countries (LDCs). Socially-oriented medical products can help to alleviate communities of ailment and disease, allowing them to flourish and develop. Medical technologies are some of the most important socially-oriented products that can help to promote global well-being and increase global wealth. Manufacturing companies who choose to engage in socially-oriented medical products not only are creating powerful technology but they are also helping to create a more robust global environment.

Governments and public authorities are encouraged to create innovation policies and eco-systems to support companies that create socially-oriented products and processes. Socially-oriented products will have a domino effect in helping to advance global progress. Academic institutions are also encouraged to educate people regarding the importance of socially-oriented products. Furthermore, the financial sector is encouraged to create specific financial assistance for these products. If more socially-oriented products are able to be created and then produced in an affordable manner, there will be great improvements that can help to uplift all global citizens.

8. Assist SMEs with Digital Transformation

Small-and-Medium Enterprises (SMEs) are a vital part of the manufacturing paradigm and account for a significant number of manufacturing business around the world. As digital technologies are now at the forefront of manufacturing practices and have become the most important enabler for competitiveness, SMEs need more assistance in this area. As SMEs have historically struggled with technological adoption as compared with large multi-national companies, it is imperative that the manufacturing community assist SMEs with the new age of digital transformation.

It is key to expose SMEs to new technologies and provide them with information regarding technological adoption and integration. With the vast amount of technology available, these tasks are often daunting to smaller companies as they do not have the readily available resources as many large manufacturing organisations do. Therefore, it is important to create conditions and tools for clustering and knowledge sharing among SMEs. By promoting knowledge sharing, trust will be fostered among SMEs and entry barriers will be lowered for new companies starting the process of digital transformation.

Policymakers are encouraged to utilise national innovation funds to create information and competence centres to become a central place for exchange of information, new learning opportunities, technology transfer, new technology testing, and increasing technological readiness. By having information and assistance readily available to SMEs, it is easier to understand and promote technological adoption.

Further, it is useful to benchmark companies in order to create a competitive atmosphere that will inspire organisations, particularly SMEs, to engage in digital transformation. By creating a competitive sector, more organisations will be encouraged to explore digital transformation and adopt new technologies. In addition, it is recommended to have opportunities for international collaboration in order to identify megatrends that are shaping the future of SMEs and the entire manufacturing sector. By allowing for opportunities to engage in knowledge sharing and collaboration, SMEs will be able to engage on a global arena to understand later implement technological innovations that are crucial to global relevance.

Finally, it is key to promote knowledge of financial information and support in order to make funding opportunities more visible to SMEs. Often public bodies have opportunities for financial incentives or funding for SMEs that are working to implement new digital technologies. Assisting SMEs with digital transformation is key promoting a robust global manufacturing sector.

9. Explore the Real Value of Data in Manufacturing

Within the *Fourth Industrial Revolution*, digital technologies are providing low-cost access to a large quantity of data from products and processed. This access to data is unprecedented and has allowed decision makers the means to access the knowledge that is implicit within this data. However, the data that is accessible to companies is not exclusively useful for just one business but rather their entire supply network including customers and policymakers. Therefore, stakeholders are encouraged to explore the value of data driven cognitive manufacturing to help improve products and processes within global supply networks.

While data is still associated with products and processes, it is not yet considered on its own as a factor of production such as raw material, capital, labour, and energy. Stakeholders must create a way to measure the value and productivity of data as part of the whole production process. Data that is acquired within a company can be incredibly valuable once properly analysed and viewed in context of both processes and global supply networks. When companies and their supply networks view and begin to utilise data as a resource in and of itself, they begin to unlock doors to understanding how to improve and streamline processes. Therefore, data must start to be considered as a vital part of any production processes in order to understand and incorporate valuable information.

However, there are potential barriers to utilising and sharing data. This is why utilising data as its own resource must become a priority. By setting up cybersecurity measures and making a concerted effort to incorporate data into decision making processes, companies open the doors to new knowledge that can greatly help to improve their organisation.

10. Promote Resource Efficiency and Country Specific Environmental Policies

Despite technological innovation, research and policies, environmental health and sustainability is still a major issue worldwide. While many countries have taken great action in terms of awareness creation for both consumers and producers, there is still a great amount of action that must be taken. As global citizens, there is one common earth and environmental issues will impact all regardless of borders and national identities. Therefore, everyone must act to promote resource efficiency with respect to individual domestic environmental policies.

For various levels of industrial maturity that exist on the planet, there are different policy needs in terms of growth rate and participation in environmental sustainability. One policy cannot fit the needs of all nations. While a standardised global agenda on sustainability is ideal, often LDCs are less sensitive to the green economy. Since LDCs are at the beginning of industrialisation they are often more focused on overall progress and implementation rather than meeting high environmental standards that are more targeted towards industrialised nations. Therefore, there is a need for customisation of such policies according to the industrial maturity of the country to remain sensitive to the industrial needs of each individual nation. Progress shouldn't be hindered because nations at the beginning of their industrial development do not have the resources to operate as efficiently as already industrialised nation. However, this should not be used as an excuse to not engage in environmental sustainability. As global citizens, all must engage in promoting environmentally friendly efforts to the extent each individual nation allows.

Further, governments, educational institutions, and industry should invest more in education and awareness of environmental issues and sustainability initiatives. By understanding the importance and implications of sustainability, more will become committed to creating and implementing environmentally conscious policies. Specifically, the circular economy and environmental sustainability should be addressed throughout all the education levels. If these concepts are understood in the core of educational systems, then products and processes will become more environmentally conscious. Additionally, as many examples show, companies remain financially healthy while they adhere to environmental policies. As a result, policymakers should consider environmental policies as drivers of financial health of companies. There is reward both environmentally and economically when these policies are put in place. However, economic success should be decoupled from resource consumption. Industry is encouraged to become innovators in sustainability even when it does not the most economical option.

Finally, the academic community is encouraged to keep working on key performance indicators for sustainability. This will stimulate companies to adopt holistic sustainability indexes in their decision-making processes and business practices. Environmentally friendly and responsible resource use should be respected by all. As use of natural resources and zero environmental harm is unavoidable, it is important to employ advanced technology for best practices. Companies should maximise efficiency of resource utilisation such through extraction and refinement processes and incorporate efforts to reduce and eliminate waste and harmful emissions.

Conclusion

The *2018 WMF Report – Recommendations for the Future of Manufacturing* addresses relevant manufacturing issues, outlines the most significant trends in manufacturing, as well as provide key recommendations for decision makers globally. The report is supported by high-level industrial, government and academic representatives to guarantee its international authoritativeness. Thus, the 2018 WMF Report serves as a white paper on the future of manufacturing by providing a set of guidelines for industrial stakeholders and beyond. It aims to support societal prosperity through manufacturing in order to promote global resilience. In light of this, the report paints a future vision of the manufacturing industry, provides a rich perspective on why organisations need to transform rapidly, explains six future-oriented visions and provides ten key recommendations for the manufacturing industry to adopt. Furthermore, it provides a holistic perspective of potential implications of manufacturing trends for both business and society.

The manufacturing industry currently has a window of opportunity to act through industrial transformation that will inspire education, sustainable development and societal impact. However, this transition cannot be successfully achieved by any single actor. As demonstrated by the WMF recommendations, it will require collaborative efforts across the value chain, involving individuals, the private sector, the public sector, and policymakers to proactively shape a new, positive future for manufacturing. This will be a future crafted by the manufacturing community's vision rather than one simply created through inertia. To achieve this goal, individuals have a key role in creating demand and pushing companies to consider societal well-being as a key factor. Companies need to design their products, processes and manufacturing systems while keeping global resilience and societal prosperity in mind. The public sector has to play its part in making necessary infrastructure available. In particular, policymakers are asked to formulate policies and regulations that incentivise innovation, especially considering new IT technologies such as Artificial Intelligence and big data, without imposing burdens that hinder growth.

We believe this report will serve as a valuable tool to move beyond the current manufacturing landscape as well as will stimulate and support a proactive management of the significant changes already underway.

References

1. The World Manufacturing Forum was established and trademarked by the Intelligent Manufacturing Systems program d.b.a IMS International Inc. All Rights Reserved.
2. Manyika, James, Susan Lund, Michael Chui, Jacques Bughin, Jonathan Woetzel, Parul Batra, Ryan Ko, and Saurabh Sanghvi. *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation. Report. McKinsey Global Institute. December 2017. Accessed September 5, 2018.* https://www.mckinsey.com/~/media/McKinsey/Featured Insights/Future of Organizations/What the future of work will mean for jobs skills and wages/MGI-Jobs-Lost-Jobs-Gained-Report-December-6-2017
3. Dröll, Peter, and Luca Polizzi. 2018. "Re-Finding Industry: Report from the High-Level Strategy Group on Industrial Technologies." In Brussels, Belgium: European Commission. https://ec.europa.eu/research/industrial_technologies/pdf/re_finding_industry_022018.pdf.
4. Ibid.
5. Ibid.
6. Ibid.
7. European Economic and Social Committee. 2017. Investing in a Smart, Innovative and Sustainable Industry A Renewed EU Industrial Policy Strategy. European Commission. https://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-479-F1-EN-MAIN-PART-1.PDF.
8. International Trade Association. n.d. *2016 Top Markets Report: Manufacturing Technology*. https://www.trade.gov/topmarkets/pdf/Manufacturing_Technology_Executive_Summary.pdf.
9. Ibid.
10. Ibid.
11. International Trade Association. 2016. *2016 Top Markets Report Industrial Automation. International Trade Association.* https://www.trade.gov/topmarkets/pdf/Industrial_Automation_Executive_Summary.pdf
12. Ibid.
13. Goedde, Lutz, Maya Horii, and Sunil Sanghvi. 2015. "Pursuing the Global Opportunity in Food and Agribusiness." *McKinsey & Company*, July 2015. https://www.mckinsey.com/industries/chemicals/our-insights/pursuing-the-global-opportunity-in-food-and-agribusiness.
14. Ibid.
15. Massey, Tracey. 2018. "A Roadmap for Pushing Manufacturing Forward." *Industry Week*, May 16, 2018. https://www.industryweek.com/print/431542 Ibid.
16. Ibid.
17. Schaeffer, Eric. 2017. *Industry X.0: Realizing Digital Value in Industrial Sectors*. Munich, Germany: Redline Verlag
18. Jankowski, Simona, James Covello, Heather Bellini, Joe Ritchie, and Daniela Costa. 2014. "The Internet of Things: Making Sense of the Next Mega-Trend." Insights. Goldman Sachs. September 3, 2014. https://www.goldmansachs.com/insights/pages/internet-of-things/iot-report.pdf
19. Ibid.
20. Schaeffer, Eric. 2017. *Industry X.0: Realizing Digital Value in Industrial Sectors*. Munich, Germany: Redline Verlag
21. Ibid.
22. MHI, and Deloitte. 2018. "The 2018 MHI Annual Industry Report." Rep. *The 2018 MHI Annual Industry Report*. MHI and Deloitte. https://www.mhi.org/publications/report
23. Ibid.
24. SAS and Datanami. 2018. "Drive Next Generation Performance with Real-Time Connected MANUFACTURING." Rep. *Drive Next Generation Performance with Real-Time Connected MANUFACTURING*. SAS. https://www.sas.com/sas/offers/18/next-generation-performance-manufacturing-109408.html?gclid=EAIaIQobChMI9Py-w-6i2wIVAoXVCh3KawyTEAAYASAAEgLHvPD_BwEG:/Team Drives/WMF 2018/00 Industry X.0/next-generation-performance-manufacturing-109408.pdf.
25. Coleman, Chris, Satish Damodaran, Mahesh Chandramouli, and Ed Deuel. 2017. "Making Maintenance Smarter Predictive Maintenance and the Digital Supply Network." Deloitte Insights. Deloitte. May 9, 2017. https://www2.deloitte.com/insights/us/en/focus/industry-4-0/using-predic-

tive-technologies-for-asset-maintenance.html.

26. Ibid.

27. Ibid.

28. Schaeffer, Eric. 2017. *Industry X.0: Realizing Digital Value in Industrial Sectors*. Munich, Germany: Redline Verlag

29. Ibid.

30. IMF Staff. 2018. "Technology and the Future of Work." Rep. T*echnology and the Future of Work.* International Monetary Fund. https://www.imf.org/external/np/g20/pdf/2018/041118.pdf.

31. Ibid.

32. Gruen, David. 2017. "Technological Change and the Future of Work." *AIFE Forum*. Lecture presented at the AIFE Forum, December 7.

33. Kagermann, Henning, Wolfgang Wahlster, and Johannes Helbig. 2013. *"Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0."* German Federal Ministry of Research and Education. https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf.

34. Ibid.

35. Huizinga, Geert, and Patrick Walison. 2017. "Smart Industry: Dutch Industry Fit for the Future." Rep. *Smart Industry: Dutch Industry Fit for the Future*. FME. http://smartindustry.nl/wp-content/uploads/2017/08/opmaak-smart-industry.pdf.

36. "Global Manufacturing Competitive Index." 2016. Rep. *The Deloitte Center for Industry Insights*. Deloitte. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-gmci.pdf

37. ICF, GHK, and Cedefop. 2014. "EU Skills Panorama 2014." Rep. *EU Skills Panorama 2014*. European Union. https://skillspanorama.cedefop.europa.eu/sites/default/files/EUSP_AH_AdvManufacturing_0.pdf.

38. "2017 Global Digital IQ® Survey: 10th Anniversary Edition A Decade of Digital: Keeping Pace with Transformation." 2017. Rep. *2017 Global Digital IQ® Survey: 10th Anniversary Edition a Decade of Digital: Keeping Pace with Transformation.* PwC. https://www.pwc.com/ee/et/publications/pub/pwc-digital-iq-report.pdf.

39. IW Staff. 2017. "Skilled Wage Growth Less Robust, Worker Shortage Still an Issue." Industry Week, October 23, 2017. https://www.industryweek.com/talent/skilled-wage-growth-less-robust-worker-shortage-still-issue.

40. Fantini, P, M Pinzone, and S Perini. 2017. "Jobs & Skills 4.0: Quale Evoluzione per Professioni, Competenze e Formazione?" Rep. *Jobs & Skills 4.0: Quale Evoluzione per Professioni, Competenze e Formazione?* Industry 4.0 Observatory of Politecnico di Milano. https://www.osservatori.net/it_it/pubblicazioni/jobs-skills-4-0-quale-evoluzione-per-professioni-competenze-e-formazione.

41. Geyer, Anton, Fabiana Scapolo, Mark Boden, Tibor Dory, and Ken Ducatel. 2003. "The Future of Manufacturing in Europe 2015-2020 The Challenge for Sustainability." Rep. *The Future of Manufacturing in Europe 2015-2020 The Challenge for Sustainability.* The European Commission and The Institute for Prospective Technological Studies. https://www.manufacturing-policy.eng.cam.ac.uk/futures-documents-folder/eu-the-future-of-manufacturing-in-europe-2015-2020-the-challenge-for-sustainability/view.

42. Mavrikios, D., N. Papakostas, D. Mourtzis, and G. Chryssolouris. 2011. "On Industrial Learning and Training for the Factories of the Future: a Conceptual, Cognitive and Technology Framework." *Journal of Intelligent Manufacturing* 23 (3): 473–85. https://doi.org/10.1007/s10845-011-0590-9

43. "ActionPlanT - The European ICT Forum for Factories of the Future." 2012. Community Research and Development Information Service. European Commission. 2012. https://cordis.europa.eu/project/rcn/95333_en.html.

44. Krupp, Fred. 2018. "How Technology Is Driving a Fourth Wave of Environmentalism." Global Agenda. World Economic Forum. May 23, 2018. https://www.weforum.org/agenda/2018/05/how-technology-is-driving-a-fourth-wave-of-environmentalism/.

45. Krupp, Fred. 2018. "Welcome to the Fourth Wave: A New Era of Environmental Progress." EDF Blog. The Environmental Defense Fund. March 21, 2018. https://www.edf.org/blog/2018/03/21/welcome-fourth-wave-new-era-environmental-progress..

46. Environmental Defense Fund, and KRC Research. 2018. "Business and the Fourth Wave of Environmentalism: Findings from Environmental Defense Fund's 2018 Fourth Wave Adoption Benchmark Survey." Rep. *Business and the Fourth Wave of Environmentalism: Findings from Environmental Defense Fund's 2018 Fourth Wave Adoption Benchmark Survey*. Environmental Defense Fund. https://utility.edf.org/apps/files/business_and_the_fourth_wave.pdf.

47. Ibid.

48. IBM. 2017. "IBM Announces Major Blockchain Collaboration with Dole, Driscoll's, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods, Unilever and Walmart to Address Food Safety Worldwide." IBM Newsroom. IBM. August 22, 2017. https://www-03.ibm.com/press/us/en/pressrelease/53013.wss.

49. Ibid.

50. United States Census Bureau, Wan He, Daniel Goodkind, and Paul Kowal. 2016. *An Aging World: 2015 International Population Reports. An Aging World: 2015 International Population Reports*. Washington, DC: U.S. Government Publishing Office. https://www.census.gov/content/dam/Census/library/publications/2016/demo/p95-16-1.pdf.

51. López-Gómez, Carlos, David Leal-Ayala, Michelle Palladino, and Eoin O'Sullivan. 2017. "Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses." Rep. Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses. UNIDO. https://institute.unido.org/wp-content/uploads/2017/06/emerging_trends_global_manufacturing.pdf

52. United States Census Bureau, Wan He, Daniel Goodkind, and Paul Kowal. 2016. *An Aging World: 2015 International Population Reports. An Aging World: 2015 International Population Reports*. Washington, DC: U.S. Government Publishing Office. https://www.census.gov/content/dam/Census/library/publications/2016/demo/p95-16-1.pdf.

53. Ibid.

54. Population Division Staff. 2017. "*World Population Prospects The 2017 Revision Key Findings and Advance Tables*." Rep. World Population Prospects The 2017 Revision Key Findings and Advance Tables. United Nations. https://esa.un.org/unpd/wpp/publications/files/wpp2017_keyfindings.pdf. .

55. Ibid.

56. United Nations. 2015. "World Fertility Patterns 2015." Rep. *World Fertility Patterns 2015*. United Nations Economic and Social Affairs. https://esa.un.org/unpd/wpp/publications/files/wpp2017_keyfindings.pdf.

57. Goldberger, Amanda, Mark Kramer, Flynn Lund, and Kate Tallant. n.d. "*The Global STEM Paradox*." Rep. The Global STEM Paradox. FSG and the New York Academy of Sciences. https://www.nyas.org/media/15805/global_stem_paradox.pdf.

58. Ibid.

59. Ibid..

60. Ibid..

61. Bourke, Juliet, Bernadette Dillon, Murray McIntosh, and Jane Lewis. 2013. "Waiter, Is That Inclusion in My Soup? A New Recipe to Improve Business Performance." Rep. *Waiter, Is That Inclusion in My Soup? A New Recipe to Improve Business Performance*. Deloitte and Victorian Equal Opportunity and Human Rights Commission. https://www2.deloitte.com/content/dam/Deloitte/au/Documents/human-capital/deloitte-au-hc-diversity-inclusion-soup-0513.pdf.

62. Reynolds, Alison, and David Lewis. 2017. "Teams Solve Problems Faster When They'Re More Cognitively Diverse." *Harvard Business Review*, March 30 2017. https://hbr.org/2017/03/teams-solve-problems-faster-when-theyre-more-cognitively-diverse.

63. "Employment by Activities and Status." 2018. OECD. OECD. 2018. https://data.oecd.org/emp/employment-by-activity.htm.

64. "OECD Economic Outlook." 2017. Rep. *OECD Economic Outlook*. OECD. https://www.oecd-ilibrary.org/economics/oecd-economic-outlook-volume-2017-issue-1_eco_outlook-v2017-1-en.

65. Fetterolf, Janell. 2017. "In Many Countries, at Least Four-in-Ten in the Labor Force Are Women." FactTank: News in the Numbers. Pew Research Center. March 7, 2017. http://www.pewresearch.org/fact-tank/2017/03/07/in-many-countries-at-least-four-in-ten-in-the-labor-force-are-women/.

66. Giffi, Craig, Trina Huelsman, Michelle Drew Rodrigue, and Katherine McClelland. 2017. "Women in Manufacturing: Stepping up to Make an Impact That Matters." Rep. *Women in Manufacturing: Stepping up to Make an Impact* That Matters. Deloitte and Manufacturing Institute. https://www2.deloitte.com/us/en/pages/manufacturing/articles/women-in-manufacturing-industrial-products-and-services.html.

67. World Health Organization and the World Bank. 2011. "World Report on Disability." Rep. *World Report on Disability*. United Nations. http://www.who.int/disabilities/world_report/2011/report.pdf.

68. "Sickness, Disability and Work: Breaking the Barriers." 2010. Rep. *Sickness, Disability and Work: Breaking the Barriers*. OECD. http://www.oecd.org/publications/sickness-disability-and-work-breaking-the-barriers-9789264088856-en.htm.

69. Department of Economic and Social Affairs. 2017. "International Migration Report 2017." Rep. International Migration Report 2017. United Nations. http://www.un.org/en/development/desa/population/migration/publications/migrationreport/docs/MigrationReport2017_Highlights.pdf.

70. "Foreign-Born Unemployment." 2017. OECD Data. OECD. 2017. https://data.oecd.org/migration/foreign-born-unemployment.htm#indicator-chart.

71. "Jobs for Immigrants: Labour Market Integration in Austria, Norway, and Switzerland." 2012. Rep. *Jobs for Immigrants: Labour Market Integration in Austria, Norway, and Switzerland*. Vol. 3. OECD Publishing. https://read.oecd-ilibrary.org/social-issues-migration-health/jobs-for-immigrants-vol-3/key-findings_9789264167537-3-en#page1.

72. Immigration Policy Center. 2012. "VALUE ADDED: Immigrants Create Jobs and Businesses, Boost Wages of Native-Born Workers." American Immigration Council. January 2012. https://www.americanimmigrationcouncil.org/sites/default/files/research/Value_Added_updated_011212.pdf.

73. Kende, Michael. 2015. "3 Numbers That Explain the Digital Divide." World Economic Forum. World Economic Forum. August 20, 2015. https://www.weforum.org/agenda/2015/08/three-numbers-explain-mobile-digital-divide/.

74. Ibid.

75. Ibid.

76. Bilbao-Osorio, Benat, Soumitra Dutta, and Bruno Lanvin. 2014. "The Global Information Technology Report 2014." Rep. *The Global Information Technology Report 2014*. World Economic Forum. http://www3.weforum.org/docs/WEF_GlobalInformationTechnology_Report_2014.pdf.

77. Sanou, Brahima. 2017. "ICT Facts and Figures 2017." International Telecommunications Union. 2017. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf. .

78. Ibid.

79. Ibid.

80. "Advanced Threat Analytics." 2018. Microsoft. 2018. https://www.microsoft.com/en-us/cloud-platform/advanced-threat-analytics.

81. Castelli, Christopher. 2018. "Revitalizing Privacy and Trust in a Data Driven World: Key Findings from the Global State of Information Security Survey 2018." Rep. Revitalizing Privacy and Trust in a Data Driven World: Key Findings from the Global State of Information Security Survey 2018. PriceWaterhouseCoopers. https://www.pwc.com/us/en/cybersecurity/assets/revitalizing-privacy-trust-in-data-driven-world.pdf.

82. Rosenberg, Matthew, Nicholas Confessore, and Carole Cadwalladr. 2018. "How Trump Consultants Exploited the Facebook Data of Millions." *The New York Times*, March 17, 2018. https://www.nytimes.com/2018/03/17/us/politics/cambridge-analytica-trump-campaign.html.

83. "Foreign Born Employment Data." 2018. OECD Data. OECD. 2018. https://data.oecd.org/migration/foreign-born-employment.htm.

84. Department of Economic and Social Affairs. 2017. "International Migration Report 2017." Rep. International Migration Report 2017. United Nations. http://www.un.org/en/development/desa/population/migration/publications/migrationreport/docs/MigrationReport2017_Highlights.pdf. Ibid.

85. Jaumotte, Florence, Ksenia Koloskova, and Sweta C. Saxena. 2016. "*Impact of Migration on Income Levels in Advanced Economies*." Rep. Impact of Migration on Income Levels in Advanced Economies. International Monetary Fund. https://www.imf.org/en/Publications/Spillover-Notes/Issues/2016/12/31/Impact-of-Migration-on-Income-Levels-in-Advanced-Economies-44343.

86. López-Gómez, Carlos, David Leal-Ayala, Michelle Palladino, and Eoin O'Sullivan. 2017. "Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses." Rep. *Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses.* UNIDO. https://institute.unido.org/wp-content/uploads/2017/06/emerging_trends_global_manufacturing.pdf.

87. Weber, Silke. 2014. "Facts and Forecasts: Where Mobility Is Going." Pictures of the Future. Siemes. October 1, 2014. https://www.siemens.com/innovation/en/home/pictures-of-the-future/mobility-and-motors/urban-mobility-facts-and-forecasts-where-mobility-is-going.html.

88. "Vital Signs of the Planet." 2018. National Aeronautics and Space Administration. 2018. https://climate.nasa.gov/.

89. Ibid.

90. Mengpin, Ge, Johannes Friedrich, and Thomas Damassa. 2018. "6 Graphs Explain the World's Top 10 Emitters." World Resources Institute. November 25, 2018. https://www.wri.org/blog/2014/11/6-graphs-explain-world's-top-10-emitters.

91. National Bureau of Economic Research, Peng Zhang, Olivier Deschenes, Kyle C Meng, and Junjie Zhang. 2017. *Temperature Effects on Productivity and Factor Reallocation: Evidence from a Half Million Chinese Manufacturing Plants.* Washington, DC. http://www.nber.org/papers/w23991.

92. Ibid.

93. The International Resouce Panel. 2012. "The International Resource Panel, Responsible Resource Management for a Sustainable World: Findings from the International Resource Panel." Rep. *The International Resource Panel, Responsible Resource Management for a Sustainable World: Findings from the International Resource Panel.* United Nations. https://wedocs.unep.org/bitstream/handle/20.500.11822/10580/responsible_resource_management.pdf?sequence=1&isAllowed=.

94. Ibid.

95. "Trade in Raw Materials." 2018. OECD. 2018. http://www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm.

96. Day, Will, Leo Johnson, Jon Williams, Caroline Herweijer, and Emma Cox. 2018. "Climate Change and Resource Scarcity." PwC Megatrends. PriceWaterhouseCoopers. 2018. https://www.pwc.co.uk/issues/megatrends/climate-change-and-resource-scarcity.html.

97. Ibid.

98. BP. 2018. "BP Statistical Review of World Energy." Rep. *BP Statistical Review of World Energy.* BP. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf.

99. "Top 20 Facts About Manufacturing." 2018. National Association of Manufacturers. 2018. http://www.nam.org/Newsroom/Top-20-Facts-About-Manufacturing/.

100. Ibid.

101. "Future of Work: The Global Talent Crunch." 2018. Rep. *Future of Work: The Global Talent Crunch.* Korn Ferry. https://infokf.kornferry.com/rs/494-VUC-482/images/KF - Future of Work - Talent Crunch Final - Email_single pages.pdf.

102. Manetti, Pierfranceso. 2017. "Smart Manufacturing: Global Footprint, Local Reach." SCM World. Gartner. November 28, 2017. http://www.scm-world.com/smart-manufacturing-global-footprint-local-reach/.

103. "Data Analytics Operational Analytics Can Transform the Utility." 2018. DailyCADCAM. 2018. http://www.dailycadcam.com/data-analytics-operational-analytics-can-transform-the-utility/.

104. US Energy Information Administration. 2017. International Energy Outlook 2017. https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf.

105. Wright, Ian. 2016. "Manufacturing Sector Identified as Leading Target of Infrastructure Cyber-Attacks." Engineering.com. May 6, 2016. https://www.engineering.com/AdvancedManufacturing/ArticleID/12050/Manufacturing-Sector-Identified-as-Leading-Target-of-Infrastructure-Cyber-Attacks.aspx.

106. Wuest, Thorsten, Patrick Schmid, Brian Lego, and Eric Bowen. 2017. "*Overview of Smart Manufacturing in West Virginia.*" Rep. Overview of Smart Manufacturing in West Virginia. ureau of Business & Economic Research And Industrial and Management Systems Engineering West Virginia University College of Business and Economics West Virginia University Benjamin M. Statler College of Engineering and Mineral Resources. https://business.wvu.edu/files/d/7c66a299-d80d-4668-b45d-01aca7c10c4c/overview-of-smart-manufacturing-in-west-virginia.pdf.

107. Ibid.

108. Foresight. 2013. The Future of Manufacturing: A New Era of Opportunity and Challenge for the UK. The Future of Manufacturing: A New Era of Opportunity and Challenge for the UK. Government Office for Science, London. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/255923/13-810-future-manufacturing-summary-report.pdf.

109. Brousell, David, Sath Rao, and Jeff Moad. 2017. "Vision 2030: The Factory of the Future." Rep. Vision 2030: The Factory of the Future. Frost & Sullivan Manufacturing Leadership Council. https://www.intel.com/content/dam/www/public/us/en/documents/white-papers/factory-of-the-future-vision-2030.pdf.

110. Zhang, Jiani. 2017. "Cognitive Manufacturing & Industry 4.0." IBM. March 17, 2017. https://www.ibm.com/blogs/internet-of-things/manufacturing-industry-4-0/.

111. Breitgrand, David. 2014. "Collaborative Manufacturing as a Service in the Cloud." IBM. December 3, 2014. https://www.ibm.com/blogs/research/2014/12/collaborative-manufacturing-as-a-service-in-the-cloud/.

112. López-Gómez, Carlos, David Leal-Ayala, Michelle Palladino, and Eoin O'Sullivan. 2017. "Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses." Rep. *Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses.* UNIDO. https://institute.unido.org/wp-content/uploads/2017/06/emerging_trends_global_manufacturing.pdf.

113. Zhou, Feng, Yangjian Ji, and Roger Jiao. 13AD. "Affective and Cognitive Design for Mass Personalization: Status and Prospect." *Journal of Intelligent Manufacturing* 24 (5): 1047–69. https://web.a.ebscohost.com/abstract?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=09565515&AN=90246130&h=t1Ae0XoERRAegxuIY1wyk1Nq4cF/fGuGzDJ6cj89Ue3v5EBh1YllTrSQjyowQ18Z31jo66aVWjX4Lt-53W2w==&crl=c&resultNs=AdminWebAuth&resultLocalhttps://web.a.ebscohost.com/abstract?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=09565515&AN=9024

114. Mears, Laine, Mohammed Omar, and Thomas R. Kurfess. 2019. "Automotive Engineering Curriculum Development: Case Study for Clemson University." *Journal of Intelligent Manufacturing* 22 (5): 693–708. https://link.springer.com/article/10.1007/s10845-009-0329-z.

115. Jimenez, Javier. 2018. "An Illustration of a Brain Surrounded by Neural Imagery. Agsandrew, Thinkstock, Getty Images TECHNOLOGY AND IIOT 5 Ways Artificial Intelligence Can Boost Productivity." Industry Week. May 22, 2018. https://www.industryweek.com/technology-and-iiot/5-ways-artificial-intelligence-can-boost-productivity.

116. Zoghby, Jeriad, Scott Tieman, and Javier Pérez Moiño. 2018. "Making It Personal." Accenture. 2018. https://www.accenture.com/t20180503T034117Z__w__/il-en/_acnmedia/PDF-77/Accenture-Pulse Survey.pdf#zoom=50.

117. Arica, Asena. 2017. "Adidas Sneakers Will Be Created Entirely By Robots From Now On." Digital Agency Network. October 5, 2017. https://digitalagencynetwork.com/adidas-sneakers-will-created-entirely-robots-now/.

118. Arica, Asena. 2017. "JWT Released The Future 100: 2018 As An Annual Forecast Of The Upcoming Year's Trends." Digital Agency Network. December 19, 2017. https://digitalagencynetwork.com/jwt-released-the-future-100-2018-as-an-annual-forecast-of-the-upcoming-years-trends/.

119. Isaac, David. 2015. "The UK in 2030: Key Trends for Manufacturing." Rep. *The UK in 2030: Key Trends for Manufacturing*. Pinsent Masons. https://www.pinsentmasons.com/PDF/BitC-Pinsent-Masons-the-Future-of-Manufacturing.pdf.

120. "Practical Pathways to Industry 4.0 The Obstacles to Digital Transformation and How Manufacturers Can Overcome Them." 2018. Rep. *Practical Pathways to Industry 4.0 The Obstacles to Digital Transformation and How Manufacturers Can Overcome Them*. Siemens. https://www.siemens.com/content/dam/webassetpool/mam/tag-siemens-com/smdb/financing/whitepapers/sfs-whitepaper-practical-pathways-to-industry.pdf.

121. Afzal, Bilal, Muhammad Umair, Ghalib Asadullah Shah, and Ejaz Ahmed. 2017. "Enabling IoT Platforms for Social IoT Applications: Vision, Feature Mapping, and Challenges." *Future Generation Computer Systems,* December. https://www.sciencedirect.com/science/article/pii/S0167739X17312724.

122. Hulse, Gavin. 2018. "What Is the Future of Blockchain in Manufacturing?" Instrumentation and Control. February 2018. http://www.instrumentation.co.za/9104a.

123. ManuFUTURE – EU High-Level Group. 2018. "ManuFUTURE Vision 2030 A Competitive, Sustainable and Resilient European Manufacturing." Rep. *ManuFUTURE Vision 2030 A Competitive, Sustainable and Resilient European Manufacturing*. European Union. http://www.rm-platform.com/images/DOCUMENTS/ManuFUTURE_Vision-2030_VC_30_05_2018.pdf.

124. A Circular Economy in the Netherlands by 2050. 2016. A Circular Economy in the Netherlands by 2050. The Government of the Netherlands. https://www.government.nl/documents/policy-notes/2016/09/14/a-circular-economy-in-the-netherlands-by-2050.

125. Gunasekaran, A., Subramanian, N., Yusuf. Y. (2018) Strategies and practices for inclusive manufacturing: twenty-first-century sustainable manufacturing competitiveness, International Journal of Computer Integrated Manufacturing, 31:6, 490-493, https://doi.org/10.1080/0951192X.2018.1463664

126. Van Den Heuvel, Rob. 2015. "The Birth of Circular Manufacturing." Manufacturing Global. November 23, 2015. https://www.manufacturingglobal.com/lean-manufacturing/birth-circular-manufacturing.

127. "Towards the Circular Economy: Accelerating the Scale-up across Global Supply Chains." 2014. Rep. *Towards the Circular Economy: Accelerating the Scale-up across Global Supply Chains*. The World Economic Forum and the Ellen MacArthur Foundation. http://www3.weforum.org/docs/WEF_ENV_TowardsCircularEconomy_Report_2014.pdf.

128. "Inclusive Manufacturing Forum." 2017. IMF. 2017. http://nias.res.in/inclusivemanufacturing/

129. Arya, Vedpal, and S.G. Deshmukh. 2018. "Product Quality in an Inclusive Manufacturing System: Some Considerations." *Journal of Intelligent Manufacturing*, May. https://link.springer.com/article/10.1007/s10845-018-1423-x#citeas. .

130. Gunasekaran, Angappa, Nachiappan Subramanian, and Yahaya Yusuf. 2018. "Strategies and Practices for Inclusive Manufacturing: Twenty-First-Century Sustainable Manufacturing Competitiveness." *International Journal of Computer Integrated Manufacturing* 31 (6): 490–93. https://www.tandfonline.com/doi/full/10.1080/0951192X.2018.1463664.

131. Manetti, Pierfranceso. 2017. "Smart Manufacturing: Global Footprint, Local Reach." SCM World. Gartner. November 28, 2017. http://www.scmworld.com/smart-manufacturing-global-footprint-local-reach/..

132. Lackey, Mike. 2013. "Why Responsive Manufacturing Is More Crucial Than Ever." SAPInsider. July 1, 2013. https://sapinsider.wispubs.com/Assets/Articles/2013/July/Why-Responsive-Manufacturing-Is-More-Crucial-Than-Ever.

133. López-Gómez, Carlos, David Leal-Ayala, Michelle Palladino, and Eoin O'Sullivan. 2017. "Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses." Rep. *Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses*. UNIDO. https://institute.unido.org/wp-content/uploads/2017/06/emerging_trends_global_manufacturing.pdf.

2018 KEY RECOMMENDATIONS BY THE WORLD MANUFACTURING FORUM:

- Cultivate a Positive Perception of Manufacturing
- Promote Education and Skills Development for Societal Well-being
- Develop Effective Policies to Support Global Business Initiatives
- Strengthen and Expand Infrastructures to Enable Future-Oriented Manufacturing
- Encourage Eco-Systems for Manufacturing Innovation World-Wide
- Create Attractive Workplaces for All
- Design and Produce Socially-Oriented Products
- Assist SMEs with Digital Transformation
- Explore the Real Value of Data-Driven Cognitive Manufacturing
- Promote Resource Efficiency and Country Specific Environmental Policies

World Manufacturing Foundation
Global Headquarters:
Via Pantano, 9 - 20122 Milano, Italy
Via Lambruschini, 4/b - 20156 Milano, Italy
-
www.worldmanufacturingforum.org