MOBILIZAÇÃO EMPRESARIAL
PELA INOVAÇÃO

Indústria 2027

mei MOBILIZAÇÃO EMPRESARIAL PELA INOVAÇÃO

IEL

Iniciativa da CNI - Confederação
Nacional da Indústria

INDÚSTRIA 2027

Riscos e oportunidades para o Brasil

diante de inovações disruptivas

PRODUTO 4

POSITION PAPER

ESPECIALISTA INTERNACIONAL

Peter Marsh

Maio de 2018

INDÚSTRIA 2027

Riscos e oportunidades para o Brasil

diante de inovações disruptivas

PRODUTO 4

POSITION PAPER

ESPECIALISTA INTERNACIONAL

Peter Marsh

Maio de 2018

IEL/NC

Superintendência IEL

FICHA CATALOGRÁFICA

I59e

Instituto Euvaldo Lodi. Núcleo Central.
Position Paper / Instituto Euvaldo Lodi, Peter Marsh -- Brasília : IEL/NC, 2018.
35 p. il. (Indústria 2027 : riscos e oportunidades para o Brasil diante de inovações disruptivas)

1. Cluster Tecnológico 2. Sistemas Produtivos I. Título

CDU: 631

IEL
Instituto Euvaldo Lodi
Núcleo Central
Sede
Setor Bancário Norte
Quadra 1 – Bloco C
Edifício Roberto Simonsen
70040-903 – Brasília – DF
Tel.: (61) 3317-9000
Fax: (61) 3317-9994
http://www.portaldaindustria.com.br/iel/

Serviço de Atendimento ao Cliente - SAC

Tels.: (61) 3317-9989 / 3317-9992
sac@cni.org.br

THE FUTURE OF MANUFACTURING:
OPPORTUNITIES FOR BRAZIL

Peter Marsh
May 2017

Do not circulate. Do not quote.

This paper has been prepared as part of the project "Industry 2027 and Disruptive Innovations: Risks and Opportunities for Brazil". It is contracted by the Brazil National Confederation of Industry to the Institute of Economics of the Federal University of Rio de Janeiro in partnership with the Institute of Economics of the Campinas State University.

Sumário

1. INTRODUCTION

A revolution is stirring

The past decade has seen heightened interest in the way new forms of manufacturing could ignite growth in countries in both the developed and developing parts of the world. Behind this have been two factors. Powerful technologies have emerged with the potential to transform manufacturing. And both established companies and start-ups have embraced new ways to organise their businesses on a global basis to take advantage of the new ideas.

The new thinking has stimulated discussion about manufacturing being on the brink of another "revolution" to add to the several that have transformed the sector from the 18th century onwards. Commentators have categorised these periods of changes in several ways. One concept (favoured by this author) is that the world is being affected by the "fifth industrial revolution (1). Behind this include the increased convergence and impact of new technologies; greater customisation of products; a bigger focus towards services in manufacturing; expanded use of supply chains and information networks; use of manufacturing to combat environmental damage and climate change; and the re-emergence as an economic force of China. Of these elements, the role of technology is most important. Engineers and researchers (helped by a more imaginative approach by companies) have brought about "technology blending": the combination of different technologies within a specific type of product or service. The concept of technology blending - as in an ability to integrate electronics capabilities with genetic engineering expertise to create new sorts of medical diagnosis products and services - is fundamental to the industry changes now being observed and will be explored in detail later in this paper.

Digital technology is a key. New ideas in electronics and information processing are based on powerful computing techniques helped by artificial intelligence (or machine learning). Artificial intelligence describes the development of computer systems able to perform tasks normally requiring human intervention. The tasks include visual perception, speech recognition and reacting to external influences in a non-routine manner. The digital technology leads to digital networks connecting products with "intelligence" embedded in them (leading to the development of the so-called internet of things); the growing use of new manufacturing equipment including 3D printing (or novel additive manufacturing); and greater capability in designing new products using computer simulation.

In one example of the power of digital tools to permit technology blending, a combination of new sensors, control devices, data analytics, cloud computing and the internet of things has created sophisticated control systems for factories, commercial premises and homes. The new equipment can regulate energy use, the flow of materials to and from production processes and entry of people.

But digitalisation is not the whole story. Other technologies will play a big part. They include non-digital ways to make new materials such as metals and inorganic chemicals, bio processing, new cutting and shaping systems for production and imaging technologies that will change the way information is transmitted and assimilated.

The links between many of these technologies will lead to new opportunities. These will provide a platform for some businesses to prosper while others will fall back (2,3,4,5,6, 29). The winners from the new industrial revolution will feature a range of companies, both big and small, and including representatives from the rich nations in the main industrial blocs, plus businesses from the faster growing but less economically established regions of Asia and South America. The enterprises that succeed will be the ones that understand the new forces at work and use them to their advantage.

This paper will spell out what are the main ideas that will drive on the new industrial revolution, revolving around broad changes in the geography of production and the capabilities of companies together with more specific shifts in technology and business practices. The businesses that can respond most adroitly to the changes, by introducing new ideas, altering their internal management processes and forging new partnerships in the world outside, have the best chance to come through the revolution as winners, leaving others by the wayside.

Report outline

This paper has been prepared as part of the project "Industry 2027 and Disruptive Innovations: Risks and Opportunities for Brazil". It is contracted by the Brazil National Confederation of Industry to the Institute of Economics of the Federal University of Rio de Janeiro in partnership with the Institute of Economics of the Campinas State University.

The paper sets out to examine: a) the nature of manufacturing and how it is changing; b) relevant technologies and new methods of business organisation; c) "technology providers" that can develop technologies to assist an economy such as Brazil's; d) "technology users" that capitalise on these ideas; e) how these two sets of players can be stimulated and assisted by government agencies and the private sector ; f) challenges and opportunities for industries in countries like Brazil, with specific attention to the diffusion of disruptive innovations, implications for workers and the identification of exemplar businesses that can act as role models to inspire others.

The paper adopts the conventional methodology for splitting the world into "developed" and "developing" countries depending on their different states of economic development. Developed nations mean countries in western Europe, the US, Canada, Japan, Australia and New Zealand. The developing nations include all the other countries.

The paper is the work of Peter Marsh and opinions in it including judgements regarding companies to choose as exemplars of specific approaches are solely down to him.

2. MANUFACTURING IN THE WORLD ECONOMY

The nature of manufacturing

Manufacturing is the business of making things. It has provided the world with the tools for creating economic wealth. Only 118 chemical elements – the building blocks of the universe – have been identified. Of these fewer than 100 occur naturally. Manufactured items are used to satisfy needs in a small number of basic areas including entertainment, food, shelter, transport, clothing, fighting, education and sex. Within these confines, people have shown impressive skills and imagination. The number of unique items made worldwide runs to 10^6 (1 with 6 zeroes after it) or 10bn (1). There are many more possibilities. In theory, the number of chemical compounds capable of being fabricated is more than 10^60 (7).

On broader grounds, there are plenty of other reasons we should be interested in manufacturing. In most countries, the sector accounts for a large part of each nation's total technology-based activity. Manufacturing businesses are more likely than most other companies to engage in research and development. They generally employ (as a proportion of their workforce) more people with high technical skills such as engineers, scientists and craftsmen and women. Average wage levels are normally high. The products and services created by manufacturers are often associated with innovation. The new ideas and thinking can transfer out to other sectors in a way that can be beneficial economically.

Average productivity (as well as productivity growth) is normally higher in manufacturing than in most other sectors, a result of relatively high levels of capital intensity and money spent on new ideas. Exports in manufacturing are almost always higher than for other areas of the economy – resulting from most sorts of goods being more adapted to trade than areas like services. There is some evidence that economies with strong, export-led manufacturing sectors typically recover from recessions faster than those without equivalent manufacturing sectors.

The sectors of manufacturing where the new ideas in technology and organisation will play a part include many that are already well established. They include automotive, aerospace, consumer equipment, industrial processing machines, telecoms and energy hardware, chemicals, medical equipment, pharmaceuticals, energy generation and distribution systems.

Within these fields, new genres will become important. Examples include autonomous cars, airborne drones, new materials based on biotechnology, novel industrial machines using techniques such as 3D printing, solar power generators, display screens based on image augmentation and medical diagnosis systems using gene technology.

Charting revolutions

Manufacturing was the principal lever with which Britain propelled itself into global economic leadership in the 19th century. This was helped by innovations developed during the first industrial revolution starting in the 1780s. They include efficient steam engines and machines to mechanise textile production. The changes ushered in the global factory age.

During the 1800s the new ideas were taken up by other developed countries. They had only a minor impact in those nations we now label as part of the developing world. Such was the power of these changes that the first industrial revolution is often referred to using capital letters: the Industrial Revolution.

Under the nomenclature adopted in this paper, the first industrial revolution was followed by four others. Again, they affected mainly the developed countries. The second revolution was triggered by mid-19th century transformations in transportation and communications technologies – such as railways and the telegraph. The third revolution (occurring around the end of the 19th century) featured science-based ideas including improved electricity generation, steel processing and the chemicals industry. The fourth revolution was the post-World War Two development of the electronic computer, triggering advances in microelectronics and the internet.

There are two main reasons why policy makers and businesses need to pay the current changes particular attention. The new industrial revolution (the fifth) will be the first to have an immediate impact on most countries including those in the developing world. Out of the total of 200 or so countries, the number where manufacturing of some sort is now significant economically is probably about 120. In the previous (fourth) industrial revolution the number of countries that were affected in the short term by the changes was probably no more than about 40. That was the number in the 1940s and 1950s where manufacturing played an important part in the lives of citizens and which contributed to wealth creation (Note these numbers are rough estimates by the author). If the number of countries affected by the new shifts is indeed some three times higher than in the previous comparable period, then this is an important reason for commentators to take notice of it.

The second reason is that the number of specific sectors of industry that the new revolution will affect is a lot higher than on the other occasions where the global pattern of industry has altered. This follows partly because manufacturing today has a vastly more complex structure than at any time hitherto. If we consider the number of different sectors and subsectors into which manufacturing can be divided (and the fact that so many of these overlap with each other and also with industrially relevant services of some description such as specialised maintenance or equipment installation) then it becomes obvious that the channels by which the effects of the revolution will feed into the global economy are considerably more numerous than was the case in previous comparable epochs. That again should amplify its impact and provide a compelling case for people who might not otherwise be interested in industrial change to want (at the least) to study its progress if not participate fully in it.

Industrie 4.0

The most widely accepted expression of current manufacturing changes is that we are experiencing not a fifth industrial revolution but a fourth one. This way of looking at the world is summed up by the term Industrie 4.0. The formulation has evolved from Germany. Here studies into Industrie 4.0 were led by led by Acatech (Germany's National Academy of Science and Engineering) and Forschungsunion, a technology research group (8). Industrie 4.0 proponents emphasise digital technologies almost to the exclusion of all the others (There is also no room in this methodology for the mid-18th century communications and transport revolution, explaining the number of revolutions implied in the title.)

The momentum behind Industrie 4.0 is impressive. A considerable number of businesses and commentators have lined up behind the German idea that we are in the fourth industrial revolution not the fifth one, and that Industrie 4.0 is the best way of summing up the current period of change and opportunity. The organisations espousing this view include such well known groups as the World Economic Forum and top business consultancies including McKinsey and Boston Consulting Group. While on the topic of differing views over the methodology of counting industrial revolutions, it is important to point out that some other commentators have argued that we are in neither the fifth or fourth revolution but the third (9,10,11).

These various ways of summing up the changes in industry - chiefly the Industrie 4.0 concept - have many merits and cannot be ignored. But they are not necessarily the best way to describe and analyse the current period. The author of this paper prefers the broader treatment of manufacturing change - treating this as the fifth in the series and calling it the new industrial revolution. It is this outline of change which will be further examined in the paper.

Changes in the geography of production

In the early 18th century, before the Industrial Revolution took off in the UK, China had been the world's biggest country in manufacturing output for at least 700 years. By around 1850 Britain (capitalising on the first industrial revolution) became the world's top manufacturing power. For the rest of the 19th century and the early part of the 20th, manufacturing was predominantly a developed country activity, led by Western Europe and North America. By the early 20th century the US and Germany had both overtaken the UK in industrial output.

More recently manufacturing has fuelled increased wealth creation and better living standards in countries including Japan (from the 1960s), South Korea (1980s onwards) and China more recently. That led to many policy makers in developing nations to study manufacturing as a way to boost growth and to provide jobs as part of a shift away from agriculture.

The rise in prominence of developing countries in manufacturing led to big changes in the shares of manufacturing done by this part of the world. In 2010 the amount of manufacturing that took place in countries outside the main developed bloc reached 41 per cent of the world total compared to 27 per cent in 2000 and 24 per cent in 1990.

In the forefront of these developments was China (12). In the 19th and early 20th centuries China had lost its way as an economic force. In 1990 its share of global manufacturing output was 3 per cent. As a result of the opening of the country to foreign investments, plus an increased interest by China's policy makers in using manufacturing as a growth tool, this share rose to 7 per cent in 2000 and to almost 20 per cent in 2010.

As this happened policy makers in many developed countries (particularly the US and UK) shifted their attention to other parts of their economies. There was a perception that production had less to offer in terms of wealth creation and employment than other sectors particularly in services. Financial services such as banking and insurance were highlighted.

The 2008-10 financial market upheavals ushered in a change in mindset. In many nations, realisation dawned that they might have set too much store on services as engines for economic expansion, and failed sufficiently to take into account opportunities from novel genres of manufacturing.

The new thinking in the developed world was aided by indications that the rapid rise in China's manufacturing output has been levelling off. There is now less talk of companies "offshoring" production from high-wage economies to low-wage regions including Asia, and more discussion of "reshoring" – manufacturing shifting in the opposite direction.

Behind this have been both economic factors such as the steep rise in wage rates in China together with an increased confidence in many western nations that local firms (armed with some of the new industrial thinking) are in a better position to compete. The ideas of the new industrial revolution have also been embraced by many developing countries. They believe the ideas may help them to continue their overall economic progress.

3. BRAZIL

Brazil under pressure

Brazil is the world's fifth biggest country by population. In2011 it was the seventh largest nation ranked by manufacturing output. In the early 2000s, Brazil seemed likely to become one of the world's star economies. It was labelled as such through the formulation of the "Brics" label - Brazil, Russia, India, China and South Africa – all countries touted to expand strongly. In Brazil's case, its role as Latin America's biggest economy and close ties to the US and other big economic powers added to the sense of promise. Many also saw positive economic after effects of the two big global sporting events scheduled for Brazil in quick succession – the World Cup of 2014 followed two years later by the Olympic Games.

After these high hopes the past few years have been profoundly disappointing. Brazil was not the only member of the Brics group to have experienced economic troubles. Of all the Brics nations, only China, and to a lesser degree India, have experienced anything like the expected progress. The main reason for the broad malaise affecting the Brics nations was the 2008-10 financial crisis that plunged the whole world into recession.

In Brazil, special factors have also been at work: increasing indebtedness levels of companies and families, public accounts getting out of control and constant delays in investments in infrastructure. These challenges contributed to the fall from power of former President Dilma Rousseff who was impeached in 2016. A series of corruption scandals involving top companies and government figures added to the damage. They burst into public view in 2014 with a probe by Brazilian judicial agencies into money laundering and bribery allegations levelled at state owned oil giant Petrobras.

Rousseff had won the 2014 on the back of popular measures to stimulate the economy through a system of price controls and special tax breaks. But, surprisingly, she shifted policy directions towards a fiscal conservatism and the economy collapsed in 2015. Brazil sank into its worst recession on record with growth shrinking by 3.8 per cent that year and 3.6 per cent in 2016. There were high hopes that the new president Michel Temer (brought to office following Rousseff's demise) could make a difference. Temer's government managed to put a cap on public expenditures and has also set out to promote pension reform and changes in labour legislation. But in May 2017 a new period of nervousness took hold after it seemed likely that Temer could be implicated in the corruption investigations, adding to Brazil's economic strains. From the perspective of the issues dealt in this paper, the problematic macroeconomic and political scenario led to deep falls in investment levels: 10.2% in 2016 in relation to the previous year.

Manufacturing in Brazil

Brazil has a broad industrial base but for some years has recorded low levels of efficiency and productivity compared to other nations. Added to this, Brazilian manufacturing has been negatively affected by the economic and political traumas of recent years. Output in this sector, along with other areas of the economy, has fallen sharply during the crisis years.

One of the best ways of monitoring this is to look at the changing share of Brazil in world manufacturing output, expressed using standardised figures from the UN statistical office.

According to these data, in 2000 Brazil was the 12th biggest nation in the world in manufacturing output (as measured in current year US dollars). By 2011, the country had risen to number seven in the world league table, with only China, the US, Japan, Germany, South Korea and Italy ahead. In that year Brazil accounted for 2.7 per cent of all world manufacturing output.

By 2015 (the last year for which the figures are available) Brazil had fallen back to 12th position, with just 1.5 per cent of total output. (The 11 countries ahead of Brazil in that year were China, the US, Japan, Germany, South Korea, India, Italy, Britain, France, Mexico and Indonesia.) The weakened economy has affected Brazil's large automotive industry in particular. In the early 200s there were high hopes that Brazil would become among the world's biggest countries for car and truck production. Output of cars and commercial vehicles in Brazil reached 3.4m in 2012, double the figure in 2000. However, by 2016 the number had fallen back to 2.2m, with few people in the sector projecting much of a rebound in the years ahead.

The auto industry is among Brazil's biggest manufacturing sectors. Big automotive groups including Fiat, VW, Ford, GM, Toyota, Nissan, Renault, Peugeot-Citroen, Audi and BMW have large plants in the country. Brazil also has a strong base of auto parts makers, many of them offshoots of overseas owned companies – including several big companies from the US (including Delphi, Visteon, Meritor and Cummins Engines) and Germany (such as Bosch, Mahle and ZF). Notable Brazilian firms in this field include Iochpe-Maxion and Sabo. In the more specialised field of bus and coach production one well known Brazil based player is Marco Polo. Another big assembly sector is electronics. Brazil has several large electronics assembly plants run by global companies including LG, Flex, Foxconn and Dell.

In other fields, Brazil has some good examples of innovative manufacturing companies that are headquartered in Brazil. Among them are Embraer (aerospace), Scitech (medical equipment) , Sabo, Havaianas and Grendene (shoes/sandals), Cia Hering, Coteminas and Osklen (clothing/textiles), Reason , owned by Alstom of France (electricity generation/distribution hardware), Metalfrio (commercial refrigeration) Gerdau and Usiminas (steel), Suzano (paper/cellulose), Tigre (pipes/building materials), Natura (cosmetics),WEG (motors, controls), Adama, part of ChemChina (crop protection chemicals), Prati-Donaduzzi (pharmaceuticals), Oxiteno (paints/agrochemicals) and Duas Rodas (food flavours).

Among the promising looking or unusual small companies in manufacturing are Solar Ear, a maker of low cost hearing aids that can be charged by sunlight; Bug Agentes Biológicos, using biotech methods to create pesticides without the normal hazards to the environment; and Urban 3D, which aims to create new building structures using 3D printing machines. In spite of the pressures on Brazil manufacturing, the numbers working in this field rose from 8m to 12m between 1991 and 2014 – helped by an increase in Brazil's overall labour market.

4. KEY ELEMENTS OF THE NEW INDUSTRIAL REVOLUTION

It makes sense to split these two sets of elements into two: technologies and business organization. For an analysis of the implications for companies and governments related to these ideas, see sections 7 and 8.

TECHNOLOGIES

A range of new ideas will be important, many being combined (blended) with each other. Among them are:

3D printing. This describes a form of additive manufacturing. This not a new term – additive manufacturing also embraces welding and brazing. 3D printing describes techniques in which complex shapes are built up layer by layer from granules of plastics or metal, allowing for the creation of parts and products on a "one-off" basis much more cheaply than with current production methods. 3D printing is facilitated by new machines (many of them based around lasers) made primarily by US and European companies. Currently used mainly for testing and making prototypes, 3D printing is increasingly being applied to make production parts.

Machine deduction. Up to now computer programs follow specific rules that are written for them by human software workers. In future machines may be able to deduce plans of action by combining many pieces of information and applying what amounts to powers of deduction. In the case of a robot on an assembly line, it may be able to spot a defective part, place it in a bin, quiz other machines to find out what caused the problem and then take the necessary action to alleviate further defects all within a matter of seconds. Similar intelligence could be applied to many other items of equipment from self-driving cars and submarines to control systems for refrigerators. In medical diagnosis equipment, artificial intelligence may be blended with diagnostic techniques – based on deciphering genes for instance – to make it easier to discover or monitor disease.

"Generative" software. In an extension of the broad idea of software advances, lines of computer code are capable of mimicking evolutionary processes. In this way, they design new products in ways not evident to human designers. Generative software of this sort evolves multiple variants on an initial idea. It eliminates the least suitable iterations, creating new shapes and formats to fit in with the initial blueprint and finishing the job with a description of the product that meets the original specification but which may look and operate very differently to the way a human designer would have envisaged.

Computerised visualisation. This can be applied to many stages of the production process including design, processing and post-production service. Savings can be made if industrial products can be simulated before being made, and if industrial processes can be tested in a range of different ways before being put into action.

Massive data transfer. Data-driven supply chains greatly speed the time to deliver orders. Digital technologies can allow production to be set to meet actual rather than projected demand, reducing the need to hold inventories and lowering failure rates for new product launches. After production, embedded computer intelligence inside products – for instance goods used by consumers including watches, cars and heart pacemakers - can send data around the world to combinations of machines and people that will be able to warn of faults or advice when parts need changing. The changes here fit in with the massively growing importance of data transfer applying to virtually every business sector* (26,27).

Nanotechnology. The process applies to techniques to manipulate materials at an atomic level. Among the sectors to which the ideas can be applied is textiles and clothing. For instance, nanotechnology promises to make it possible to impregnate tiny polymers of a special design into the fibres of materials such as cotton or polyether to influence the properties of a garment. In this way, the item could be made to be ultra-water resistant or (for sports clothing) immune to sweating. Parts of an athlete's running vest could be transformed into tiny sensors that monitor the body continuously to provide feedback useful in training. Nanotechnology can also help to make new materials useful in many applications from aerospace to construction.

Synthetic biology. The term covers the application of engineering principles to biology. Proponents think the ideas could create new carbon-based substances useful in pharmaceuticals, catalysts, fuels, energy devices including fuel cells and batteries and materials to replace or supplement plastics in packaging or consumer goods.

Inorganic biology. Biotechnology up to now has been applied only to creating organic compounds – those formed from biological processes and containing carbon bonds. Scientists are now working on methods based on biotechnology to create structures also containing contain inorganic atoms such as metals. As a result, metal-like substances with new properties can be created. In such a way, new substances could be created to act as coatings n the outside of exposed structures to make them more resistance to corrosion.

Photonics. The growing convergence of light-based methods to process data together with conventional digital switching techniques (based on the electronic properties of silicon and other semiconductors) has been apparent for some time. Much work in photonics taps into developments in laser technology – used to create light in sharply defined wavelengths and intensities. Research in photonics often proceeds in parallel with related studies in materials – used either to create improved parts of specialised photonic cells or as the core components for novel lasers. Work in this field can be applied to a large spectrum of industrial sectors from consumer electronics to defence.

ORGANISATION

To take advantage of the new ideas manufacturers will alter their procedures for managing businesses to take account of the following (with many of these changes facilitated by new technology):

Technology blending. This is among the most important aspects to company organisation in the new industrial revolution. It applies to the ability to integrate different technologies to create new products and services or to improve production processes. Descriptions of technology blending, and how it is implanted, are dealt with extensively in the rest of the paper.

Product customisation. This refers to the increasing "tailoring" of products from consumer gadgets to industrial machines to suit the requirement of the user. In step with the increased requirement for customised goods are changes in technology – including more sophisticated methods of automation. These make it easier and cheaper to make small production runs of goods honed to meet the requirements of customers. The shift often makes it necessary to locate manufacturing closer to where goods will be used, so that the necessary design changes can be incorporated most effectively. That may accelerate the moved towards reshoring in at least some high cost regions while also offers opportunities for new business opportunities in developing nations.

Consumers as creators. Beyond their rising interest in personalisation and customisation, consumers are also increasingly apt to engage in the creation, or at least the conceptualisation, of the products they buy. At base, this phenomenon represents a shift in identity from passive recipient to active participant—a blurring of the line between producer and consumer. One manifestation of this trend is the growing popularity of the maker movement—a resurgence of DIY craft and hands-on production.

Niche thinking. New industries are being created in narrow areas of production (and related service activities). These are the so-called “niche” or “sliver” sectors that barely existed in the past. But today – due to changes in technology and industrial organisation, plus the new possibilities that exist for selling globally using the internet and better transport links – such narrow sectors are becoming more viable as an area in which often small industrial businesses can compete on a global basis. In most cases, niche companies are found in western nations, rather than in the emerging economies. Examples of these new niche businesses include: high-speed air-bearing spindles for drilling machines; specialised lighting using semiconductor-based re light-emitting diodes; thin, flexible steel pipes for energy exploration and medical equipment; and high-precision pumps for the food industry.

Intelligent products. Products can take on new dimensions by having computer intelligence (perhaps in the form of tiny microchips assisted by small sensors) added to the. In this way, many sorts of consumer goods including food, pharmaceuticals and clothing can become more useful and valuable both to the companies that make them and the people who buy and use them. Taking advantage of such changes is not just a question of adding new technologies to the portfolio of a company but bringing about shifts in ways of thinking.

Environmental stewardship. This concerns the way environmental factors are playing a part in influencing how companies operate, involving both the processes they use and the goods and services they sell. In the past, manufacturing companies were almost always associated with despoiling the environment. This happened either through pollution during production processes, or in the way the goods were used after they left the factory. Now, environmental factors are being used by companies much more positively, as a potential competitive advantage. Companies in existing fields from electric motors to car production are investing in new manufacturing methods or novel types of products to make their businesses more “environmentally friendly”. New industries aimed at making products whose use have environmental benefits may also be created. Examples are photovoltaic cells and wind turbines.

Service dimension. Increasingly, manufacturing concerns not just the fabrication of goods but the service elements linked not just to designing them – often to suit individual requirements – but also to maintain and safeguard them once they have left the factory. In a similar way, many manufacturers employ people who in effect provide advice and consultancy (mainly for their customers) or operate or steward machines on behalf of the businesses that buy them. The changes mean the normal distinctions between manufacturers and service businesses are starting to blur. There are plenty of examples of such "servi-manufacturing". The UK aero-engine producer Rolls-Royce gains half its revenues from making engines and selling them to aircraft manufacturers or airlines. The other half comes from organising a service contract with the customers such that they pay Rolls-Royce to maintain the products once they are flying.

Networked manufacturing. The growth of global supply chains and information networks, the latter building on the internet, are key elements altering manufacturing. The same facilitates collaborative relationships between companies in different parts of the world, sometimes in widely different businesses. Capitalising on such arrangements can provide a competitive advantage to manufacturing companies based in high cost, developed nations. Even when they choose to base the physical production of goods in low-wage nations such as China, Vietnam or Morocco, the high-cost country will often be in a better position to act as the home for research and development activities. Global networking also offers new opportunities for developing nations by creating possibilities for participation in areas of manufacturing activity from which they were excluded.

Cluster mentality. Small clusters of companies and research organisations – often versed in complementary or identical technical disciplines – are often concentrated in the same geographical region. Clusters of this sort have been in evidence for a long time, sometimes centuries. The businesses in the clusters may share ideas, staff and suppliers. (They may also spy on each other to steal commercial secrets in a way that provides beneficial to some but it damaging to others). Clusters' impact will grow as globalisation widens their reach.

New economic geography. Recognising the new balance of power globally will be a vital factor for the manufacturers of future. Countries formerly considered as developing are becoming more developed. Obvious examples are China, India and Brazil. They will increasingly become important centres of technology creation, new service thinking and manufacturing capability. As a result, they will more and more become essential to the way other parts of the world organise and plan for the future. Ahead of the others by a long way in terms of influence is China. The re-appearance of this country as a manufacturing power has given a huge impetus to goods production globally.

Maverick management. Many of the most promising manufacturing businesses of the new era have at the top people with new ideas that would have been scorned in most business circles a few decades ago. The people with these new ideas might still find it hard to convince others that they should be given a chance. However maverick thinkers have a big part to play in the new era for industry.

5. MANUFACTURING AND JOBS

Employment trends

The big story in global manufacturing in the past 50 years has been one of rapidly rising productivity, with output rising much faster than employment – which in many countries has declined (13,14). World manufacturing output in 2014 was roughly double the figure in 1991 (measured at constant prices). Counting only output from the developing nations, here the most recent figure was four times higher than in 1991. For developed countries output was 50 per cent higher. The difference in rate of output change in the developing as opposed to the developed world is due to the shifts In the geography of production outlined earlier. Also manufacturing output in the developed world started the period from 1991 onwards from a markedly higher base than in the developing regions where manufacturing production was at the beginning of this juncture very small by comparison.

Yet for all the big increases in output in both the developed and developing regions, in neither area has employment risen at anything like the increases in production, with employment in the developed countries seeing a substantial drop.

World manufacturing in 1991 employed 325m people, according to UNIDO (15). Of these 234m were in developing nations and 91m in the developed countries. In 2014 the total had risen to 367m, with the increase being due completely to a rise in the number in the developing world to 304m, with the figure in the developed countries falling steeply to 63m.

Between 1991 and 2014, the share of manufacturing employment in the global total decreased from 14.4 percent to 11.5 per cent. Over the same period the developed nations showed a drop for the comparable numbers from 21.8 per cent to 13.2 per cent, while for developing countries the fall was a less steep 12.7 per cent to 11.2 per cent.

Some employment increases in the developing nations have come about, as might be expected, due to the fact that they now do a lot more of the world's manufacturing than used to be the case. But the bigger effect explaining the employment trends of recent decades has been labour saving technology and higher productivity. It is possible now to produce a lot more goods with fewer people –helped by a lot of clever technology.

The experience of individual nations

In the US, job numbers in manufacturing have fallen from 20m in 1980 to slightly more than 12m in 2016.According to a study by researchers at Ball State University, almost 88 percent of US job losses in manufacturing in recent years can be attributable to productivity growth (3). Had the US maintained 2000-levels of productivity and applied them to 2010-levels of production, it would have needed approximately 8m more manufacturing jobs.

Between 1991 and 2014, US manufacturing employment as a percentage of the total fell from 17.7 per cent to 9.8 per cent. In Germany, the figure went from 30.6 per cent to 19.4 per cent. In Japan, the drop was from 24.3 per cent to 17 per cent.

In developing nations, it has proved extremely hard for specific countries to push up employment in manufacturing by more than a small amount. In Poland employment in manufacturing after 1991 failed to rise from the 25.2 per cent of total employment registered in that year, with the figure declining to 19.1 per cent in 2014. In some other developing countries, the comparable numbers showed an increase early on, only to fall back. For China, the figure rose from 13.9 per cent in 1991 to 14.9 per cent in 1996, but then decreased by 2014 to 11.7 per cent.

Mexico saw a similar trend – here the number started as 16.1 per cent over the period, rose to 19.7 per cent in 2000 but then declined to 15.7 per cent – as did Brazil. In this country, the employment proportion in manufacturing was 12.9 per cent initially, rose to 14.4 per cent in 2008 and then fell back to 12.9 per cent again.

India had a slightly better record. Here manufacturing accounted for 10.9 per cent of jobs in 1991 with the proportion rising to 12 per cent in 2014. The high point for manufacturing employment during the period was in 2007 when the figure reached 12.3 per cent. The fact that the number has since come down – albeit by not very much – appears to indicate that manufacturing employment in India is already past its peak.

Is deindustrialisation spreading?

The recent indications make it appear that the developing countries are experiencing "deindustrialisation" well before what had appeared to be the schedule. Deindustrialisation is the tendency seen in developed countries for manufacturing employment to fall at a relatively late stage in these nations' cycle of economic development. It is related to the likelihood in these nations that services as a percentage of total output will climb rapidly, crowding out other sectors. This trend is exacerbated by prices of services normally rising much faster than those for industrial goods, where prices are likely to increase only slowly (or fall at least in real terms) as a result of improvements in technology and productivity.

It was always assumed that most developing countries would experience deindustrialisation– but only after a lengthy period in which employment in manufacturing rose. The recent experience of the developing countries has triggered concerns about what appear greatly reduced prospects for using manufacturing as a vehicle for job creation.

But while jobs in manufacturing may be under pressure, and not see much growth in either the developed or developing nations, there is still room for some optimism on this score.

The employment future

The employment trends in manufacturing seem likely to be assisted by new labour-saving technologies including advanced machine learning. Some observers think the changes could trigger job losses across sectors (not just industry) on a massive scale (16). A study from Oxford Martin School in the UK predicts that 47 percent of US jobs across all sectors are at a "high risk" of being threatened by automation (17). Manufacturing jobs could be affected along with others so continuing the trends in this sector in the past 20 years.

But there is another school of thought that says job losses due to massive machine learning in manufacturing will be limited – while scope for employment gains will be relatively strong. Behind this is the argument that an expanding number of jobs in manufacturing plus allied services require powers of creativity and empathy – "people skills" – that may be beyond the immediate power of machines to replicate (18,19).

At the root of this thinking is that the broad definition of manufacturing encompasses an immense range of types of job (20,21,22). One US study lists 130 occupations within manufacturing (23) while another study in the UK lists 165 (24). Many of these occupations combine manufacturing and engineering roles with a strong "services" dimension, with the latter often requiring workers to form strong bonds with other people.

Frequently it turns out that the jobs with a human dimension are growing in importance within companies (creating more vacancies) while the traditional roles involving pure mechanical and engineering skills have become less required (as a result of the automation trends already in place). An example of a "high empathy" is the sales engineer – an increasingly vital occupation in many manufacturing companies and one where skills are often in short supply.

In one study already cited (17) researchers examined more than 700 occupations across all US industries. The job categories were ranked according to the estimated ease with which they would be automated out of existence. Those at least risk in all available US jobs include several broad types of manufacturing occupations which require people skills and to do with supervision, selling, design or providing advice or instruction. Meanwhile jobs most likely to disappear include several manufacturing roles - such as hand sewers, polishers and machine adjusters – which are limited in importance and which few people would expect to see expand in significance with or without the new technologies.

The consensus from all these findings is that as technology races ahead, the jobs that will be under pressure are those to which machines will have little difficulty in adapting. One survey of young people in the US provided some optimism on this score, with many respondents believing the advent of new digital ideas in manufacturing would offer many good job opportunities (25).

It seems that in the future the manufacturing tasks that require creative and social intelligence are likely to be relatively immune from being replaced by jobs done by robots. It follows that if human workers are to win the race against machines they will need to acquire (along with technical capabilities) creative and social skills.

The way industrial jobs are likely to change as a result of new technologies, demand changes and shifts in the internal organisation of companies is bound to have a considerable impact on the skills that will be required for the next generation of industrial workers. Policy makers will need to study the shifts involved to devise the right ways to educate and train tomorrow's work forces while businesses also need to prepare in a suitable way for the future. These changes will be further explored in the final sections of this paper.

6. GLOBAL BUSINESS EXEMPLARS

Often these “role model” companies use not just one or two of the new ideas in technology or organisation but as many as six or seven. Several technologies may be applied in unison through a “blending” process. These are integrated with a number of elements related to organisation. Few companies set out to introduce new approaches in any ordered way. Most frequently it happens in an unplanned and sometimes quite chaotic manner. None the less it is is interesting to analyse how new ideas have been applied within companies and what are the main forces making things happen.

The author has chosen these examples from his own knowledge. The list is not meant to be exclusive. The author would welcome suggestions for additional names.

There are more US companies than from other countries. That seems to make sense since the US contains many examples of business innovation. The list also contains a reasonable number of businesses from Brazil as it seems a good idea (when examining Brazil) to try to find a few examples of role model companies from among the ranks of domestic firms. Any obvious omissions should be brought to the attention of the author.

US - Lightning Motorcycles. Lightning was started by Californian entrepreneur Richard Hatfield to design and make motorbikes based on electric power. The machines have been created with the help of new thinking in software and computer visualisation. Generative software designed by the US firm Autodesk was used to design an ultra-light, strong set of parts. The components that emerged from the process looked peculiar but could be manufactured effectively and did the job. **Main characteristics: maverick management, technology blending.**

US - Proteus Digital. Smart medicines that tell doctors when their patients have taken them moved a step closer to reality. Proteus makes “digital pills” that should help ensure patients stick to their prescriptions. The “smart pill” contains a tiny ingestible sensor that detects when the drug has reached the stomach. It communicates with a wearable patch on the patient’s skin which then transmits the information to a mobile device. In theory, the sensors could also be in contact with computers that are monitoring how millions of patients globally with the same ailments are taking their medicines. **Main characteristics: niche thinking, technology blending, networked manufacturing.**

US - Local Motors. The future of car manufacturing is being rethought in a stream of innovations including self driving cars. Local Motors is another company with a big name for car industry innovation. It is seeking to build a business based around made-to-order car designs. Complementing the initiative are microfactories, workshops where prototypes can be developed using processes such as 3D printing. **Main characteristics: product customisation, consumers as creators.**

France - Sigfox. Under the ideas for the internet of things, hundreds of millions of devices will be connected via digital networks. Data passed between them will carry information useful in many fields of activity. Sigfox is one of a new breed of companies providing the computer protocols making it possible for the devices to “talk” to each other effectively. The company is an expert in technologies including semiconductor design, telecoms signalling and sensors. **Main characteristics: technology blending, service dimension.**

China -Huawei. One of the world's biggest makers of smart phones, the telecoms giant has emerged as a Chinese technology champion, adept in a number of disciplines including high-power processing chips, telecoms signalling hardware, cloud computing and factory automation. Some big companies, chiefly in the US, wary of using its equipment because of worries that the company is linked to Chinese intelligence services which may use the equipment to learn about commercial secrets of overseas businesses. **Main characteristics: networked manufacturing, new economic geography, technology blending.**

UK - Brompton Bicycles. The humble bicycle can be the subject of substantial technological innovation. This is proved by Brompton, a London-based company which makes almost 50,000 foldable bikes a year. The bikes can be packed and stored, while also carried on trains. The company makes its devices in 16m variants. It makes itself or has designed three-quarters of the 1,200 mainly metal components that go into each bike. Each bike is held together by about 100 joints created by the centuries-old technology of brazing. **Main characteristics: niche thinking, product customisation**.

Ireland-PCH. The company is partly a manufacturer – making a range of goods for other companies under contract - and partly a consultant and facilitator. It derives revenues both through its work for customers such as Apple (which pay it for delivering set quantities of products such as computers or medical devices, and also for handling worldwide supply chains) and small start-ups which PCH advises on growth strategies. **Main characteristics: networked manufacturing, service dimension.**

Japan-Nidec. One of the world's top makers of small electric motors, the company's products are used in many industries including home appliances, factory automation, cars and computers. It has 96,000 employees, with its biggest factories in China. Nidec is particularly strong in controllable digital motors. Because these vary in speed and torque according to external demand, such devices can play a role in cutting energy use. Its chief executive and founder is Shigenobu Nagamori, an idiosyncratic engineer. **Main characteristics: maverick management, new economic geography, niche thinking.**

Australia-Gekko. The company started out making manufacturing equipment for separating metals in mining. It has evolved into a mix of a producer and a service company – providing to clients a spectrum of specific sorts of machines (many of them tailored to suit particular needs) plus consultancy with which the customers can make their own operations more efficient. **Main characteristic: service dimension.**

Germany –Adidas. At its German factory sportswear manufacturer Adidas plans to produce running shoes on a big scale. This is against the trend for most such items to be made in developing nations. In total, the process of making a pair of trainers from start to finish takes roughly five hours. In Adidas's existing supply chain in Asia, the same process can take several weeks. Outsourcing of sports shoe manufacturing to Asia has become unappealing for Adidas due to the 18-month time lapse between the design of new models and their arrival in stores. **Main characteristics: product customisation, global networking.**

South Africa- Agriprotein. Managing 8bn living creatures under one roof sounds a complex job. The "farms" are run by Agriprotein, a South African pioneer in animal feed. Each of Agriprotein's installations take up the space of an aircraft carrier, contain robotic equipment and environmental controls and cost about $20m. The creatures inside the farms are black soldier flies which lay eggs from which come larvae. The larvae feed on organic food waste (the "raw material" for the farms) which are then turned into high-protein animal feeds for fish farms. Agriprotein has formed partnerships with science researchers in South Africa, Spain and the UK. **Main characteristics: networked manufacturing, environmental stewardship.**

Denmark - Universal Robots. As industrial robots have evolved, one of the most widely studied applications is in the field of "collaborative" systems – robots that can work with people. The hardware contains robot arms with sensor ability so they know what nearby are doing. A leader in such collaborative robots is Universal Robots which is building up business globally and specialises in selling to small and medium sized firms. **Main characteristics explaining success: intelligent products, technology blending.**

India – Jain Irrigation Systems. Jain is a pioneer in micro-irrigation. The technology uses small amounts of water to improve crop yields. It relies on a stream of subsidiary technologies in fields such as pumps, control systems and filters, supported by knowhow related to specific types of crop. Water is supplied through thin pipes to divert it directly to plant roots. Jain uses a system of production to create installations on a customised basis. It has been helped by acquisitions of businesses (in countries including the US, Brazil and Turkey) to provide both manufacturing and technology. **Main characteristics: global networking.**

Brazil – Embraco. Founded in 1971, Embraco is a world leader in compressors – vital components in refrigerators. It supplies components to brands around the world from factories in Brazil, US, Mexico, Italy, Slovakia and China. Of its 9,000 employees 500 are engineers and technicians. It owns more than 1,000 patents and has a strong record in innovation. Among the areas of technology, it has concentrated on are "intelligent" compressors that monitor temperature and other operating conditions and adjust the way they work accordingly. **Main characteristics: niche thinking, customisation, intelligent products**.

Brazil—Embraer. The company's development into one of the world's top four aircraft makers was helped by a programme of government assistance going back to the late 1960s. In the effort to create a global aerospace industry, Brazil had to learn a lot about aircraft technology, particularly in its chosen niche of small commercial and military aircraft. Embraer was helped created a series of co-production and licensing arrangements with foreign partners (28). **Main characteristics: technology blending, niche thinking.**

Brazil-Natura. The company has created as global name in cosmetics and personal care, with its products mostly based on vegetable indigenous Brazilian fruits and vegetable. These are harvested by farmers in small communities, usually in the Amazon region, and some of the company profits are invested back into the communities. Harvesting operations are designed to be sustainable. The business was started in 1969 and has more than 7,000 employees, most of them in Brazil where it has five plants. **Main characteristics: environmental stewardship, cluster mentality.**

Brazil - Sunew. The field of solar energy is one of the most promising areas where new technology promises to have an impact. Established in 2015, Sunew is exploiting new ideas in the area of organic photovoltaics, so-called third generation solar panels, capable of generating electrical energy from sunlight. Organic photovoltaic cells have higher efficiency than previous generations based around semiconductor processing. They are made with thin, light chemical film that can be made with varying levels of transparency and colour and to highly customisable shapes. **Main characteristics: technology blending, environmental stewardship.**

7. IMPLICATIONS FOR COMPANIES

These implications can be split into three areas depending on the main areas they apply to: training, jobs and skills; technologies; and business organisation and management

Training, jobs and skills

Training and skills development add up to some of the most vital areas that need to be addressed by any business as it seeks to strengthen its competitive position. In approaching the challenges and opportunities of the new industrial revolution, firms need to look at the balance between how they provide “service” or “soft” skills in relation to the "hard " technical skills associated with engineering and science.

How much should these be brought together or kept separated? How can internal skills resources be best harnessed in attempting to meet the needs of customers while also withholding key details ("company secrets") that are vital to maintaining a firm's commercial advantage? How should firms use their skills resources to the best advantage in managing relations with suppliers and in product development? Which skills and new disciplines will be important in helping the business both strengthen its existing position and move into new areas?

The way different companies approach these questions will vary depending on the fields of commerce they are in. But it is likely that they will share several important characteristics. They will be interested in technology or (more commonly) blends of different technologies. They will have a global perspective, meaning they will either be selling in regions outside their own country (as well as in it) or will be in business areas where competition from enterprises from outside their regions is strong. And the business field they are in will be characterised by rapid change - in technology, in the regions that are important (both from the perspective of sales and of the supply of components and key technologies) and in the identities of the other players in their specific industrial field that are important competitors.

In this environment, several conclusions can be drawn on the subject of skills provision. Companies need to continually assess the skills they need to remain competitive and make an effort to add new skills or strengthen existing capabilities, depending on the conclusions from these assessments. It will generally be advisable (when filling new positions) to introduce a mix of young people with fresh ideas and energy , together with an inflow of older , more experienced people, so as to get the best balance of different mindsets and attitudes.

In looking to fill vacancies and build a basis of skills for the future, businesses that are attempting to make the most of the new opportunities should also recruit (and then do their best to retain when they are in their jobs) people who combine several key characteristics. These people should be interested in and reasonably adept in a range of technologies, and know how to use these to good effect (Many companies will find more useful a new recruit who has this combination of attributes rather than someone who is an expert in a single area of technology but is at a loss when attempting to use or get access to others).

The employees of choice will have a view of the world that goes beyond the borders of her or her country. This will make such people more valuable from the viewpoint of the employers - as well as (incidentally) equipping them with skills likely to be useful in any future career. And the most forward-looking companies will want to bring to their businesses - and develop when they are in their jobs - people who combine technical skills with an ability to communicate with and relate to others. Such a combination of capabilities will be increasingly needed in manufacturing in the 21st century.

Technologies

When thinking of the ways technologies will be useful within companies, it helps to understand what is the main "technology characteristic" of the business itself. Is it primarily a "technology provider" - a company that develops new technology or combinations of technology either for its benefit or for the use of others? Is it primarily a "technology user" - it gets access to technology through a range of channels (for instance licensing, partnerships or diffusion) that are mainly developed outside its own business? Or is it a mixture of both these types?

Another set of questions then applies to the ways in which different businesses learn about technologies and apply them. To what degree do they rely on external contacts such as connections with others via supply chains, research and development, informal liaisons or even straightforward technology diffusion such as learning about technology from competitors? The latter may include picking apart the products of competing firms in "tear down laboratories" to bring about "reverse engineering" or (less acceptably according to normal business practice) industrial espionage. Once it becomes apparent how companies - whether technology providers or users - get access to technology a second set of questions related to how good they are at the processes involved. Do the series of technology connections work smoothly? Or are there impediments that need to be addressed?

Also important in considering technologies is the range of types of technology that different enterprises depend on. Increasingly businesses require access to, and knowledge of, not just one or two technologies but a complete family of different technologies. It's not uncommon for some of the fast-moving industrial players of today to be interested (and highly knowledgeable) in a raft of types of technology that would 30 years ago been regarded as quite separate. To take just one example a company building autonomous airborne drones may well need to know about a long list of technologies including microelectronics, propulsion systems, telemetry, batteries, new materials, machine learning, advanced software, sensors and detection systems such as radar.

Several conclusions follow on from this thinking. Whether companies are providers or users of technology or are a mix of both, they must be adept at assessing technologies and how they interact with others.

While technology providers will almost certainly be good at developing completely new technical ideas that previously have eluded others, all three of these groups of businesses must be proficient in technology transfer - methods of channelling into their businesses techniques and ideas originally developed by others. Even the cleverest developers of technology in the world are extremely skilled at using ideas from others, adapting the best ones and adding new concepts to build a winning position in a specific field. Apple is just one example of a company that uses this approach.

The enterprises that come out best from the new industrial revolution will above all be consummate "technology blenders". They will be good at assembling groups of people who are experts in specific technologies and putting them alongside others who are proficient in others. When working on new product development or new sales programmes, the companies will tend to base their approach on use of multidisciplinary teams made up of people proficient in a range of technologies and also including people skilled in "softer" areas such as marketing and consumer psychology. In this way, they will get the most use out of their individual employees and give themselves a better chance of commercial success.

Business organisation and management

On the organisational dimension it seems appropriate to try to categorise the different sorts of approach to work out what are the best ways to encourage the different ways of handling the internal activities of the enterprise. For example, the mix of organisational changes germane to the new industrial revolution can be split into segments.

These can be classified as being mainly to do with the following: development of products and services; linkages between company staff with people outside the business; marketing and selling; the mix of proficiencies in which the company seeks to develop excellence; and different styles of leadership. Looked at in this way, the organisational ideas listed in the earlier section of this paper can be split into categories. Product customisation and "consumers as creators" both become part of the "development of products and services" category. Niche thinking falls partly into this same subgroup while also being part of "marketing and selling". Service dimension is part of the "proficiency mix" organisational group. Maverick management is one sort of broad type of leadership style that may have a good chance of paying off in the new industrial revolution.

Companies will need to apply a mix of organisational methods if they are to gain the best chances of success. Frequently the best way to work out which ones will work is first to study the businesses (based both inside and outside Brazil) that have both done well in technology fields and then applied different approaches of organisation. From these exemplar companies will often come lessons that can be applied to other businesses. The firms that are seeking to progress should be approach to experiment with their approaches. They should show an appropriate degree of flexibility until they find the mix of organisational approaches that work best for them.

8. IMPLICATIONS FOR POLICY MAKERS

The ideas from this paper outline the potential progress for businesses in the new industrial revolution. Much of the discussion is weighted towards companies and other parts of the private sector. But there are many implications also for policy makers that need to be addressed. In designing policies that will give companies the best chance to take advantage of the new opportunities, governments and other public authorities have to look chiefly at four areas:

a) Accelerating the development of new expertise in the technologies and management thinking that will become more important;

b) Diffusing these ideas as efficiently as possible;

c) Assisting private sector groups as they seek to capitalise on the new ideas.

d) Promoting new forms of manufacturing both to bolster public support and also to encourage more young people to enter the industry as future recruits.

In practice policies aimed at all four areas overlap. They lend themselves to most countries, not just Brazil. The chief policies required are:

- A big effort on education and publicity to illustrate the new possibilities in industry, based around giving prominence to business exemplars that demonstrate how the new thinking can be put into practice.
- Skills and training in emerging technology fields should be improved, at the level of schools and other education institutes
- Refine and share best practices for technology diffusion. As part of this companies should be encouraged to review their approaches to link up with other businesses and entities such as local schools and colleges

- Government should set principles and broad guidelines on the shape of the new industrial revolution but leave companies to set their own strategies

- Ensure the needs of small to medium sized companies are addressed in technology diffusion. While institutions for technology diffusion work with many types of firms, particular attention is needed to help these businesses navigate the next production revolution.

- Recognise that there are many success stories in manufacturing. Manufacturing needs to take some of the kudos that Silicon Valley has monopolised in the public imagination thanks to people such as Steve Jobs and his emulators as charismatic “founders”.

- Address governmental failures in technology diffusion interventions. Ensure that programmes working to upgrade existing firms (the majority of firms) are appropriately resourced, in addition to programmes that support advanced technology development and start-up enterprises.

- Ensure that government evaluation measures give more weight to long-run development of new capability rather than short-term benefits such as provision of new jobs in an institution or company where the jobs have a fragile base and may not last very long

- Recognise that effective institutions are essential for the widespread deployment of the next production revolution. Where such institutions exist, their role and mission must be integrated into next production revolution strategies. In Brazil such agencies might include institutes such Brazilian Agricultural Research Corporation (Embrapa), Brazilian Company for Industrial Research and Innovation (Embrapii), the National Electric Energy Agency (Aneel), Ministry of Science, Technology and Innovation (MCTI) , SENAI Institutes of Innovation run by the National Service of Industrial Apprenticeship (SENAI) .

9 CONCLUSIONS FOR BRAZIL

Central to this paper is to provide thoughts that may benefit Brazil as it continues to develop in manufacturing. The paper is written from an external perspective. The author does not profess to have in-depth knowledge of Brazil. The ideas in the paper apply to many other countries. There is a good chance - but no certainty- that they will prove useful to Brazil.

Behind the concept of the new industrial revolution is that the world stands on a brink of a set of new of new opportunities in manufacturing. A key to the revolution is the ability to integrate groups of technologies via a "blending" process to create new products and services that customers in a range of countries will find useful. Digital processes including new communications links, 3D printing and machine learning (artificial intelligence) are among the crucial technologies that will play a part.

Also important is a range of organisational changes that mark out the companies that will be the lead players in the revolution and take maximum benefits from it. These changes are based on ideas such as niche thinking - creating products and services with a narrow range of uses - and then finding customers for them in many countries. Another important concept is global networking ("networked manufacturing") by which businesses based in one part of the world can link up using a variety of methods with other firms located in many different places. In this way jobs including research and development, production and marketing can be spread out around a number of players in what can prove a highly versatile and efficient form of manufacturing.

For those firms aiming to capitalise on the ideas behind the new industrial revolution one big challenge (apart from working out how to use the right combination of technologies and organisational techniques) is to create conditions to embed in their business the appropriate mix of skills. Recruiting a cadre of people who can combine technical with personal capabilities is important.

As the characteristics of top manufacturing companies change, job roles requiring high levels of competence in communication - simply put, talking to others and making sure points can be made and addressed with the minimum possibilities for misunderstanding - are becoming every bit as important as the most superb technical acumen. Individuals who can combine both these elements will be valuable employees. They may also have a promising future as an entrepreneur setting up new companies. In any country having a large cohort of such people is desirable.

Clearly, it is important to consider the language or languages that people in different nations find most comfortable to use when speaking to each other. In a world where cross border business is becoming increasingly important, the fact that English has become the most widely used default business language benefits those who can use this language well. As a result, many of the manufacturing workers of the future – the subject of this part of the paper – would almost certainly do well to have a good level of competence in English.

Where in this analysis does Brazil fit? How well it poised to reap advantages from the industrial changes taking place? How much progress have individual firms in Brazil (whether indigenous companies or subsidiaries of foreign owned businesses) already made in implementing some of the new ideas? Is there a sufficient supply of skills, technologies and levels of organisational flexibility in Brazil to permit enough enterprises to move ahead? Can a mix of transformative technologies and organisational changes provide windows of opportunities for Brazilian companies to catch up and perhaps even overtake some of the global leaders?

These questions should be addressed by the participants of the current project in Brazil. It is beyond the capability of the author to provide any detailed answers at least at this stage. But a few reflections are as follows.

In the new Industrial Revolution the businesses that can respond most adroitly to the changes, by introducing new ideas, altering their internal management processes and forging new partnerships in the world outside, have the best chance to come through the revolution as winners, leaving others by the wayside. That applies generally and is also the case in Brazil.

Brazil has a big economy, the biggest in Latin America. It has close economic ties with the world's largest economies, the US, Europe, Japan and China. It appears to have a good level of industrial competence with a few outstanding companies that might be able to provide a lead on some of the ideas behind the new industrial revolution. It has made immense progress in the past 30 years in developing a decent industrial base. It has a reasonable level of technical proficiency. Many large non-Brazilian companies such as those based in Europe and the US are experienced at dealing with Brazil either through sales arms or through setting up more deeply embedded centres of competence in Brazil such as manufacturing operations.

Less positively the country has appeared to slide in overall levels of manufacturing capabilities in recent years. Partly this has been due to economic shocks. Another worrying event has been political upheaval. Of specific concern is swirl of allegations of corruption levelled against some leading Brazilian companies. These have come amid signs that top business leaders have become used to handing out bribes and other forms of inducement to senior politicians in exchange for contracts. This is hardly a propitious environment for preparing a country to take up new industrial thinking in an atmosphere of trust and transparency.

Looking ahead however it is also possible to take a more upbeat view. For all the current strains the message should come across that Brazil has a huge chance of benefiting over the next few decades from the new ideas. The elite of the country's business establishment need to understand the forces driving on the revolution. They should prepare their own organisations (plus others where they have influence) to take advantage of them. An alliance of the private sector, government organisations plus leading academic establishments should take the lead in starting a programme of education and change to plant the seeds of the new industrial revolution in Brazil and ensure that they flourish.

10. NOTE AND REFERENCES

***Note**:

On the topic of data growth, Cisco Systems has suggested that the total data contained in internet traffic in 2016 would be around 1 zettabyte (1×10^ 21 bytes). In comparison, the information contained in all books worldwide is about 480 terabytes (5 × 10^14 bytes), and a text transcript of all the words ever spoken by humans would represent about 5 exabytes (5 × 10^ 18 bytes).

References

1.The New Industrial Revolution: Consumers, Globalization and the End of Mass Production, Peter Marsh, Yale University Press, 2012

2. 21st century manufacturing, the jobs, workers and technology for a new era, Ditchley Foundation, 2017, http://www.ditchley.co.uk/conferences/past-programme/2010-2019/2016/21st-century-manufacturing

3.The Myth and the Reality of Manufacturing in America, 2015, Michael Hicks and Srikant Devaraj, Center for Business and Economic Research, Ball State University,

http://conexus.cberdata.org/files/MfgReality.pdf

4.Get Ready for the New Era of Global Manufacturing , Harvard Business Review, James Manyika, Katy George and Louis Rassey, Jan 31 2013 ,https://hbr.org/2013/01/get-ready-for-the-new-era-of-g

5. Manufacturing The Future: The Next Era of Global Growth and Innovation, James Manyika, Jeff Sinclair, Richard Dobbs, Gernot Strube, Louis Rassey, Jan Mischke, Jaana Remes, Charles Roxburgh, Katy George, David O'Halloran and Sreenivas Ramaswamy, McKinsey Global Institute, 2012, http://www.mckinsey.com/business-functions/operations/our-insights/the-future-of-manufacturing

6.The future of manufacturing -Making things in a changing world, Deloitte University Press,2015

https://damassets.autodesk.net/content/dam/autodesk/www/mech-eng-ressource-center/eng-leadership/assets/fy17-mfg-engineering-leader-deloitte-future-of-mfg-report-en.pdf

7.Software builds "library" of millions of small, carbon-based molecules chemists might synthesize, Duke University, 2013, https://today.duke.edu/2013/04/smallmolecules

8.Securing the future of German manufacturing industry, Recommendations for implementing the strategic initiative ,INDUSTRIE 4.0 ,April 2013, Final report of the Industrie 4.0 Working Group, 2013 http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf

9.The Third Industrial Revolution: How Lateral Power is Transforming Energy, the Economy, by Jeremy Rifkin, Palgrave Macmillan, 2011

10.The Third Industrial Revolution, The Economist, 2012, http://www.economist.com/node/21553017

11.The Fourth Industrial Revolution, Klaus Schwab, World Economic Forum, 2016.

12.The new industrial revolution and industrial upgrading in China: achievements and challenges, Khairy Tourk & Peter Marsh, Economic and Political Studies, 2016, http://www.tandfonline.com/doi/abs/10.1080/20954816.2016.1180769

13. Where Did All the Workers Go? 60 Years of Economic Change in 1 Graph, Derek Thompson, The Atlantic, Jan 26 2012, Https://www.theatlantic.com/business/archive/2012/01/where-did-all-the-workers-go-60-years-of-economic-change-in-1-graph/252018/

14.US Manufacturing Skills Gap, Deloitte, 2011, https://www2.deloitte.com/us/en/pages/manufacturing/articles/boiling-point-the-skills-gap-in-us-manufacturing.html

15.The Role of Technology and Innovation in Inclusive and Sustainable Industrial Development, Industrial Development Report 2016, Unido, https://www.unido.org/fileadmin/user_media_upgrade/Resources/Publications/EBOOK_IDR2016_FULLREPORT.pdf

16.Rise of the Robots: Technology and the Threat of a Jobless Future, Martin Ford, Basic Books,2015.

17.The future of employment: how susceptible are jobs to computerisation?, Carl Benedikt Frey and Michael A. Osborne, Oxford Martin School, 2013, http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf

18.Beyond Automation, Harvard Business Review ,Thomas Davenport and Julia Kirby , 2015, https://hbr.org/2015/06/beyond-automation

19.The Growing Importance of Social Skills in the Labor Market, David Deming, National Bureau of Economic Research, Working Paper No. 21473, 2015, http://www.nber.org/papers/w21473

20.Which industries will drive future jobs growth in the UK? PWC Economic Outlook, 2016, https://www.pwc.co.uk/assets/pdf/ukeo/ukeo-sectoral-employment-march-2016.pdf

21. About the Manufacturing Sector, Bureau of Labor Statistics, 2017. https://www.bls.gov/iag/tgs/iag31-33.htm

22.Employment in the US-Production Occupations, Bureau of Labor Statistics, 2017, https://www.bls.gov/ooh/management/home.htm

23.Jobs in Manufacturing and Their Titles, Breakdown in the US according to Census information, The Balance, 2016, https://www.thebalance.com/manufacturing-job-titles-2061501

24. Profiles of manufacturing and engineering, UK National Career Services, 2017,https://nationalcareersservice.direct.gov.uk/job-profiles/manufacturing-and-engineering

25. Survey on job prospects in manufacturing, Protolabs, 2017, http://www.businesswire.com/news/home/20170321006014/en/Millennials-Upbeat-Manufacturing%E2%80%99s-Future

26.Cisco VNI Forecast and Methodology, 2015-2020, Cisco Systems,2016,http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.html

27.How much information? UC Berkeley School of Information, 2003, http://www2.sims.berkeley.edu/research/projects/how-much-info-2003.

28.Interrupted Innovation: Emerging economies in the structure of the global aerospace industry, Dániel Vértesy , Maastricht University, 2011.https://www.merit.unu.edu/training/theses/vertesy_daniel.pdf

29. The Next Production Revolution: Implications for Governments and Business, OECD, 2017.

IEL/NC
Paulo Afonso Ferreira
Diretor-Geral

Gianna Cardoso Sagazio
Superintendente

Suely Lima Pereira
Gerente de Inovação

Afonso de Carvalho Costa Lopes
Cândida Beatriz de Paula Oliveira
Cynthia Pinheiro Cumaru Leodido
Débora Mendes Carvalho
Julieta Costa Cunha
Mirelle dos Santos Fachin
Rafael Monaco Floriano
Renaide Cardoso Pimenta
Zil Moreira de Miranda
Equipe Técnica

Execução Técnica
Institutos de Economia da Universidade Federal do Rio de Janeiro – UFRJ
Institutos de Economia da Universidade Estadual de Campinas - Unicamp

Peter Marsh
Autor

Luciano Coutinho
João Carlos Ferraz
David Kupfe
Roberto Vermulm
Margarida Baptista
Luiz Antonio Elias
Caetano Penna
Giovanna Gielfi
Mateus Labrunie
Carolina Dias
Thelma Teixeira
Equipe Técnica